MIT Technology Review

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New DNA Tests for the Unborn
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BUY FRESH BUY GMO

Population growth and climate change will make it harder to feed the world. We need to overcome our fears of genetically modified food.

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From the Editor

I GREW UP ON A FARM ON THE NORTH Coast of California in the 1970s. It had been a sort of commune, and after my parents bought the property, the hippies stayed on as farm workers and the place retained the style of the counterculture. Stewart Brand's *Whole Earth Catalog*, with its tools and ideas for the back-to-the-land movement, was the farm's almanac.

My father, who worked in San Francisco, had intended the farm to be a weekend retreat, like an English country home; but my mother wanted to live there and grow things. We raised free-range game birds for the restaurants of San Francisco. There were three vegetable gardens and an orchard. Everything was sternly organic.

Except of course it wasn't. By even the mid-'70s what was called "organic" was conditional: if you met various standards set by an industry's marketing association, then you were an organic farmer, although those standards were far from the natural methods the founders of organic farming had imagined. In the vegetable gardens, we tried using other insects for pest control, but nothing answered until we sprayed with *Bacillus thuringiensis* (Bt), a bacterium commonly used as a pesticide in organic farming. We bought fertilizers with fish emulsions, which did better than the farm's own manure and compost. Raising birds, we began by feeding them unadulterated cracked corn, but they didn't grow large enough for sale, and soon we were driving to Santa Rosa Feed and Game every month to purchase organically certified bird feed, whose supplemental ingredients (including vitamins and a range of proteins and amino acids), when listed on the sides of the sacks, were longer than a small boy's hand.

Outside the very poor world, all farming is like this: it is industrial. That's because even organic farmers are frightened of the blights and diseases that can destroy a harvest or covey, and they think about nothing more than increasing the yield from their land.

As David Rotman, the editor of *MIT Technology Review*, argues in "Why We Will Need Genetically Modified Foods" (page 28), the concerns of farmers are becoming more acute. The Green Revolution increased crop yields by introducing more productive crop varieties. "But for at least the past decade, increases … seem to have slowed. Yields of wheat, for example, are growing at roughly 1 percent annually; they need to increase nearly 2 percent annually to keep up with food demand over the long term. Agricultural experts warn that yields will have to improve for other crops as well if we are to feed a rapidly growing population—and yet rising temperatures and other effects of global climate change will make this tougher to achieve."

Fortunately, Rotman explains, recent genomic breakthroughs, advances in molecular biology, and new genome engineering tools allow geneticists to edit plant DNA, making changes exactly where they want on chromosomes in order to create desirable traits. The new technologies are far more sophisticated than the transgenic techniques used in the first genetically modified crops, where genes from one species were transferred into another, as the Bt genes expressing a toxin poisonous to bugs were inserted into corn and soybeans. With luck, we may be able to increase yields sufficiently to feed the nine billion people who will be alive in 2050 and design crops that can tolerate heat, drought, and new patterns of plant disease.

But we'll need to accept genetically modified foods. Today, most GM corn and soybeans feed animals or go into biofuels. No genetically modified varieties of rice, wheat, or potatoes are widely grown, although we will need these crops to feed the world. But while scientists now understand how to affect traits in plants, only large companies can afford the expense of developing GMOs, and such corporations have shied away from genetically modifying wheat, rice, potatoes, and vegetables because they fear that consumers will reject the results.

But perhaps the new order of GMOs, where plant geneticists accelerate the traditional work of plant breeders, will seem less freakish to consumers than transgenic crops do now. Perhaps, too, the new crops will seem *greener*: high-yield, disease-resistant, hardy GMOs will allow farmers to use pesticides and fertilizers less, which is truer to the organic ideal. Back in the 1970s, if my mother and I could have chosen not to bathe our vegetables with biochemicals, we would have done so.

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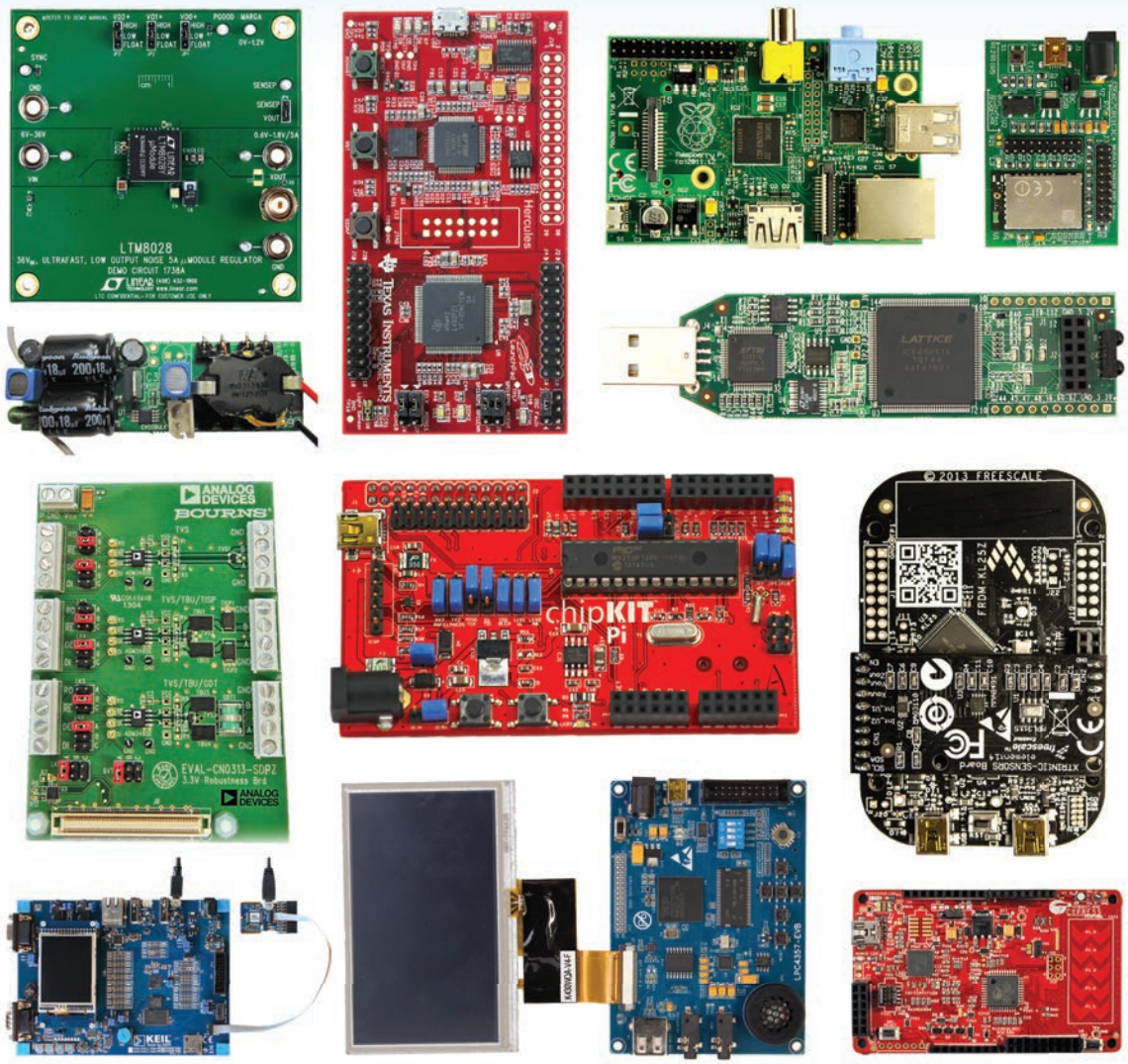

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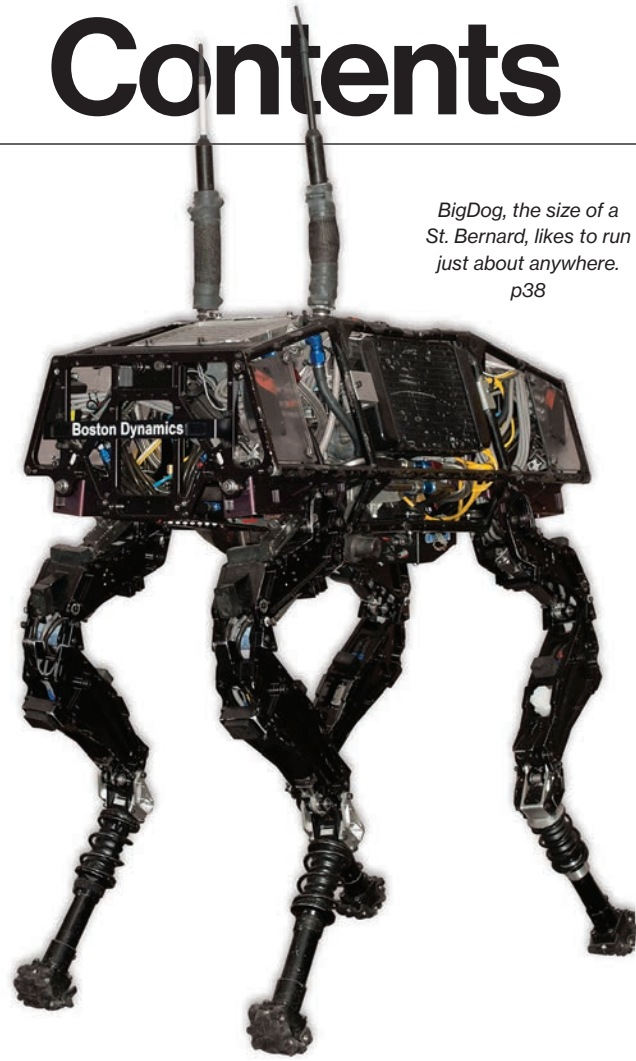

BigDog, the size of a St. Bernard, likes to run just about anywhere. *p38*

January/February 2014

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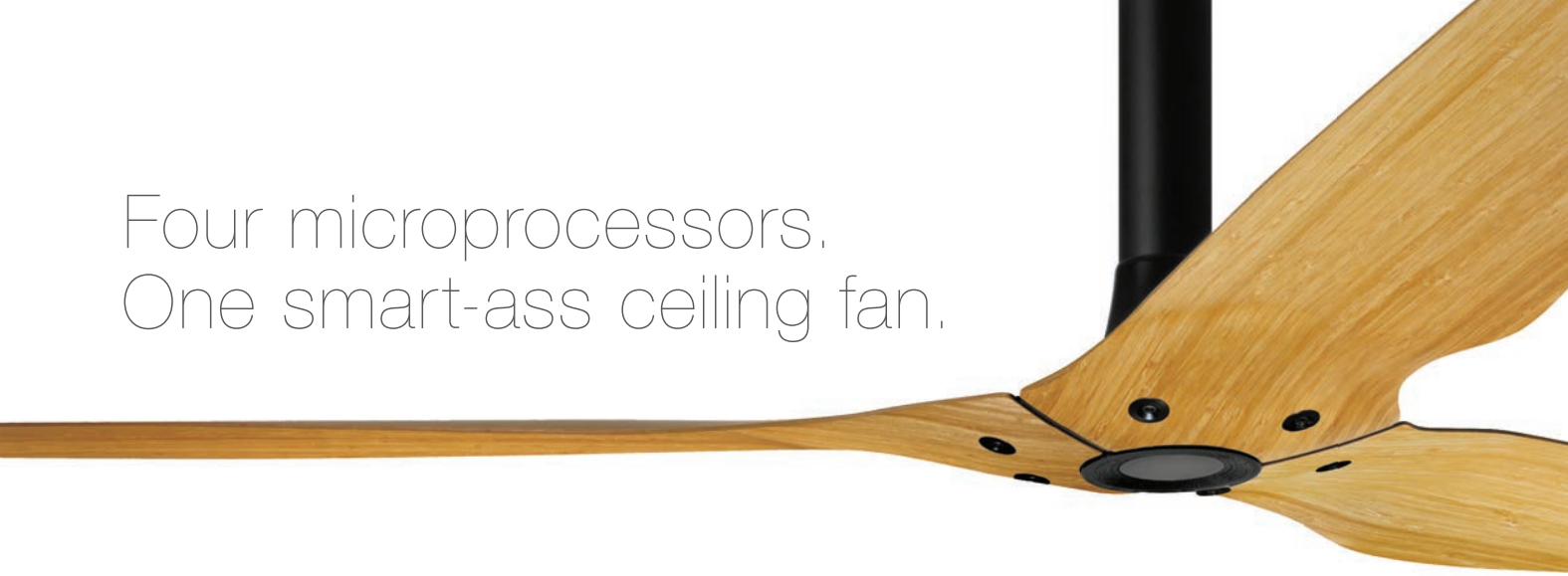
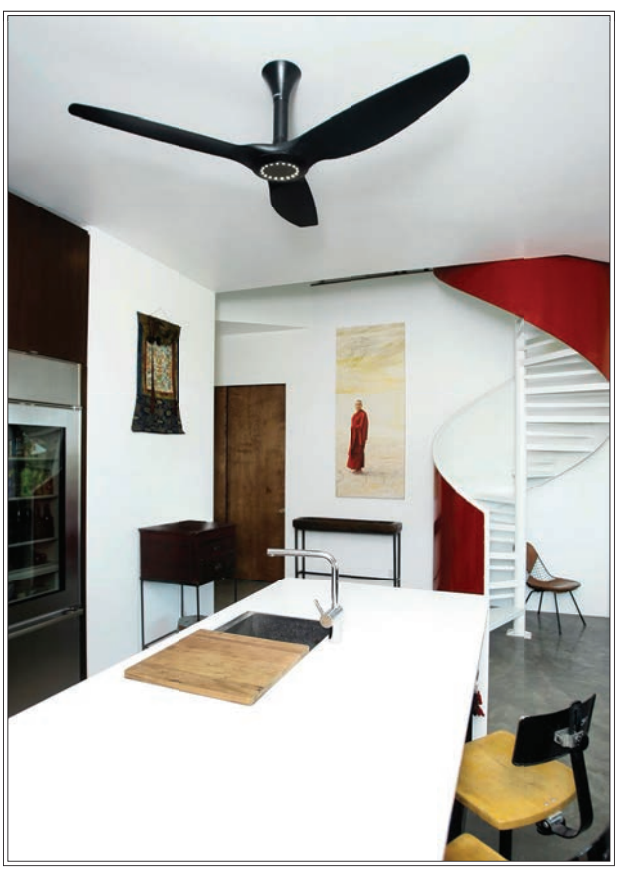
ON THE COVER:
Illustration by Justin Metz for *MIT Technology Review*

Four microprocessors. One smart-ass ceiling fan.





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Feedback

Five Most Popular Stories

MIT Technology Review Volume 116, Number 6

1

The Decline of Wikipedia

So often people say things like "Companies are moving away from the traditional hierarchical structures and toward open collaboration," yet when it actually happens in a big and obvious way, people are close to panic. I think some people actually prefer having somebody clearly in charge.

—MaxGain

There is no other website as sanctimoniously fake as Wikipedia. The site is not an exemplar of democratic principles. Quite the opposite. It has one of the most bizarre arbitrary authoritarian bureaucracies I've ever seen. **—Decimizer**

2

The Real Privacy Problem

I would not allow my personal belongings to be rummaged through and analyzed in order to discover what I might be missing in my life. Likewise, I do not want anybody or anything rummaging through my digital life in order to serve me a "better" ad. **—KennethJ**

I watch—in a combination of disgust, awe, and befuddlement—as my friends, colleagues, and even "elders" commodify and publicly detail their every breath and step. Many are in complete ignorance that their lives are being algorithmized. **—mena_nut**

3

A Tale of Two Drugs

Unlike MDs, who understand the inevitability of death, most patients opt for any and all medical interventions. Since the cost is borne by future taxpayers, and since their doctors pad their incomes no matter what the outcome, their bias toward treatment, however futile and shortsighted, is logical.

—wcordell2

The cost of developing a drug through FDA approval for sale is $1.2 billion. With such an enormous, risky cost up front, is there any question why drugs are so expensive, especially drugs which will have thousands, and not millions, of patient-purchasers?

—R Sweeney

4

Driverless Cars Are Further Away Than You Think

The author has a test drive with BMW and Mercedes-Benz and comes away singing their praises and writing off Google. Yet Google has logged thousands of incident-free miles, while BMW's prototype may or may not have braked to avoid a collision. And the reason Google is written off? Because the lidar is ugly. **—tuariki1**

It seems inevitable that fully autonomous vehicles will be introduced in some part of the world, and once they're on the road somewhere, the benefits will be impossible to deny.

—CBDunkerson

5

So Far, Smart Watches Are Pretty Dumb

Smart watches seem like prime Apple territory—an existing technology that no one else is doing right and that needs a heavy dose of design and simplification.

—ctbowers

I'd like to have a few simple ways to control the watch without having to touch it; for instance, I'd like to control my music while working out on a rowing machine. One idea would be to have sensors that could identify the movements of each finger, and let you program what each of those movements controls. That's a watch I'd like to have. **—jdrulon**

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Morozov Misses the Point

From David Brin

In "The Real Privacy Problem" (November/December), Evgeny Morozov writes: "This is the future we are sleepwalking into. Everything seems to work, and things might even be getting better—it's just that we don't know exactly why or how." That's a very cogent description of a subtle and interesting failure mode. His subsequent discussion of rights and contradictions is certainly interesting.

> **"Morozov gloms on to a 'solution' based on concealment and obscurity—one that cannot possibly work."**

Alas, Morozov then gloms on to a "solution" based on concealment and obscurity, hiding from authority—one that cannot possibly work. Like nearly every seer in this benighted field, he refuses to consider how there might be transparency and accountability-based solutions that work *with* trends toward a world awash in light, rather than raging against the tide.

He mentions Jaron Lanier's notion of people having a commercial "interest" in their own information and a right to allocate it for profit. That certainly is an improvement over the fantasy of a legal "right" to conceal your information and to punish those who have it, a stunning delusion in a world of limitless leaks. Lanier's notion is a step forward—instead of prescribing futile and delusional shrouds, it envisions a mostly open world where we all share in the benefits that large entities like corporations derive from our information.

Except that "our information" is also a delusion that will fray and unravel with time, leaving us with what is practical, what matters: how to maintain control *not* over what others *know* about us but over what they can *do* to us. And to accomplish that, we must know as much about the mighty as they know about us.

Alas, after an interesting discussion, Morozov devolves down to this: "We must learn how to sabotage the system—perhaps by refusing to self-track at all. If refusing to record our calorie intake or our whereabouts is the only way to get policy makers to address the structural causes of problems like obesity or climate change—and not just tinker with their symptoms through nudging—information boycotts might be justifiable."

This notion, that any measures taken by private persons will even slightly inconvenience society's elites in their ability to surveil us, would represent charming naïveté if it weren't a nearly universal and dangerous hallucination. In *The Transparent Society*, I discuss the alternative we seldom see discussed, even though it is precisely the prescription that got us our current renaissance of freedom and empowered citizenship: "sousveillance," embracing the power to look back and helping our neighbors to do it as well.

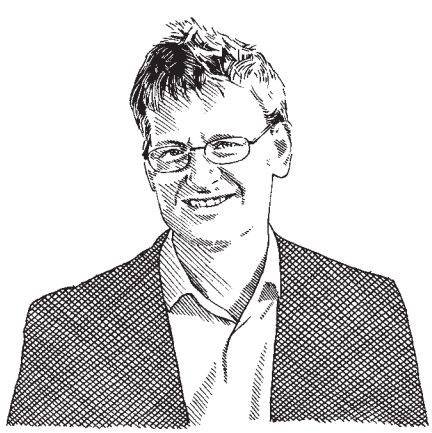
I agree with Morozov about the need for "provocative services": he almost seems to get the core idea, that we can solve most of these problems through open, polite, and fair confrontation, of the sort that teaches people to behave like adults. An intriguing essay. And yet, again, missing the central point of our age.

David Brin's numerous works of fiction include the short story "Insistence of Vision," part of *MIT Technology Review*'s new science fiction anthology, *Twelve Tomorrows*. He also wrote the nonfiction book *The Transparent Society: Will Technology Force Us to Choose Between Privacy and Freedom?*

Views

M. Anthony Lewis

Julie Shah



Mark Lynas

COMPUTING

Brainy Chips

We should look to biology to figure out how to make smartphones more helpful, says M. Anthony Lewis.

A modern smartphone is the most powerful information portal the world has known, integrating a traditional telephone with a powerful Internet-connected computer capable of navigating, playing multimedia, and taking photos. I think the next major step in smartphone evolution is obvious: the devices will become intelligent assistants that can perceive the environment and follow our commands. This will become possible thanks to progress in building chips inspired by the functioning of mammalian brains (see "Thinking in Silicon," page 52).

We hope to achieve what I call embedded cognition—intelligence that resides on the mobile handset itself rather than on a distant server. We want devices that are always listening, watching, and paying attention to us, without compromising battery life. We need new kinds of algorithms to process streams of sensory data from sights, sounds, physical sensations, and more. We need our phones to be capable of learning so that they can come to understand their owner. And we need to stuff this intelligence inside compact, power-efficient hardware because we don't want to transmit data off the smartphone for processing—a requirement that causes delays for users of Apple's Siri and the Google Now app for Android phones.

A team of engineers and neuroscientists at Qualcomm Research is working on a new type of processor to meet those challenges. It takes design cues from the human brain, which despite using only about 20 watts of power is the most impressive and efficient "computer" that we know of at processing data from the real world—the kind we want smartphones to handle too.

The Zeroth processor, as it is called, works on data using silicon "neurons" that are linked into networks and communicate via electrical spikes. A system with a Zeroth processor can learn. In one test, researchers trained a wheeled robot to favor certain areas of a room by rewarding it when it was in the correct place. We also envision sensors modeled on the nervous system. They would conserve energy by reporting only when the environment had changed, instead of transmitting data constantly at all times.

This biologically inspired approach to computing should pave the way for the next major upgrade to the 130-gram marvel we call the smartphone.

M. Anthony Lewis is lead engineer on Qualcomm's Zeroth project.

ROBOTICS

Among Us

Robots will be more useful when they can work alongside us, says Julie Shah.

Traditionally, robots were designed to work separately from people. That is starting to change as robots begin working alongside humans to courier medicine in hospitals and assemble complex machinery. New legged robots could soon accompany soldiers across treacherous terrain or perform rescue missions at stricken nuclear power facilities (see "The Robots Running This Way," page 38). But for the most part, robots still can't function in human environments without requiring costly changes to people's own working patterns.

Researchers are now beginning to understand how to build robots that

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Views

can integrate seamlessly and safely into human spaces. One approach is to give them more humanlike physical capabilities. A human-size robot with legs, arms, and hands can use the same pathways, doors, and tools that we do, so the environment need not be laboriously retrofitted. Of course, a robot does not have to do a job the same way as a person. The Roomba vacuum cleaner appears to bounce randomly around the room, while we would employ a more efficient and methodical approach. However, the Roomba, unlike us, has only one job to do and does not get bored or impatient. In designing a robot's physical capabilities, we must think carefully about the context in which it will be deployed and remember it isn't necessarily bound by the considerations guiding the way people work.

The same applies as we begin to design robots intelligent enough to work alongside people. It is as impractical to redesign our work practices for robots as it is to redesign our physical world for them. We must instead build robots capable of doing their jobs with only minimal disruption to the people they work with or near.

This will require them to have mental models of what governs our actions. Robots can build these models the same ways people do: through communication, experience, and practice. We do not require that robots have our full human capabilities for decision-making, communication, or perception. Through careful study of effective human work practices, my own research group is designing robots with planning, sensing, and communication capabilities suited to their contexts. For example, our assembly-line robot learns when to retrieve the right tool by observing its human coworkers, without necessarily having to ask. Robots like this one work seamlessly with people and reduce the economic overhead of deploying new systems. As a result, it will soon be practical to extend human capability through human-robot teamwork.

Julie Shah is an assistant professor at MIT and leads the Interactive Robotics Group.

GENETIC MODIFICATION

Good Crops

Crops that aid humanitarian causes may soften opposition to genetic modification, says Mark Lynas.

As a former anti-GMO activist, I have bitter experience of the unpleasantly polarized debate about the merits of GMOs. But that experience makes me see how we might respond to people's fears without banning a vitally important technology.

The lack of middle ground in this debate does not mean that each side has an equivalent claim to truth. The overwhelming scientific consensus, as stated by the American Association for the Advancement of Science, the World Health Organization, and many other expert bodies, is that transgenic crops are as safe as unmodified ones.

But the scientific consensus on GMO safety has little impact on anti-GMO activists. It is at odds with their worldview, and they simply cannot accept it psychologically. GMOs encapsulate activists' fears about technological hubris, industrial food production, and the economic power of multinationals.

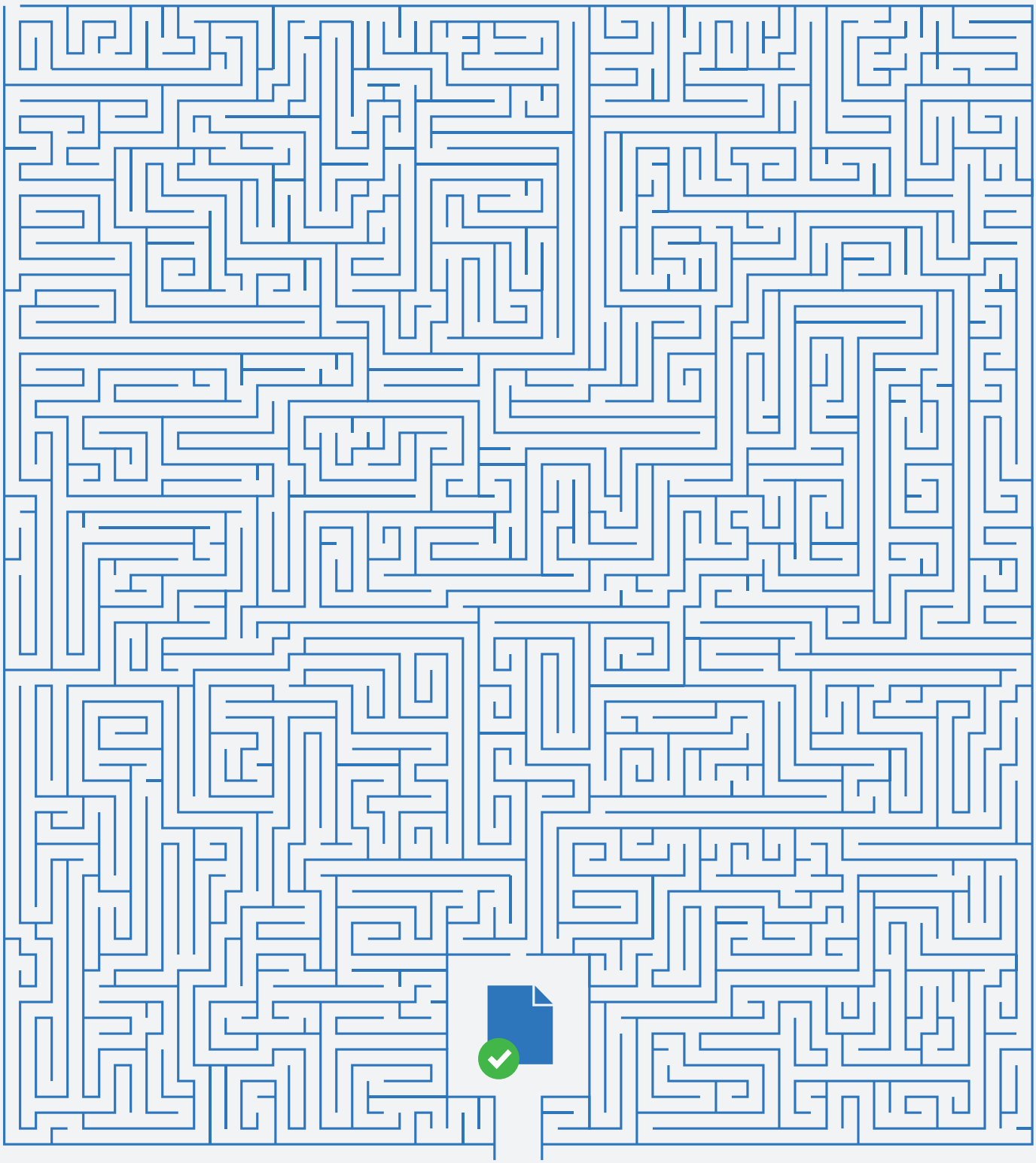
One way forward is to demonstrate that GMOs can be deployed in ways that explicitly promote the values and political goals motivating their opponents (see "Why We Will Need Genetically Modified Foods," page 28). These crops can reduce the use of environmentally damaging agrochemicals, and several have been developed by public-sector organizations concerned with food security, the reduction of poverty, and sustainability.

One example is a genetically modified eggplant variety known as Bt brinjal, recently approved by the government of Bangladesh. This crop has been developed by an international partnership of universities and public-sector institutions, led by Cornell University (where I am a visiting fellow involved with the project) and the Bangladesh Agricultural Research Institute. The modified crop is resistant to a caterpillar called the fruit and shoot borer, which destroys as much as half of Bangladesh's eggplant harvest. It eliminates the need to spray with insecticides that expose farmers and consumers to carcinogenic residues. Extensive scientific trials have shown the crop to be safe for human consumption, and farmers will be encouraged to save seed from one year to the next.

Golden rice, genetically engineered to produce beta carotene, provides another example of how GMOs can serve the values that motivate their opponents. It was developed to reduce vitamin A deficiency, which is estimated to cause two million deaths annually, mainly in young children. Golden rice is owned by an independent humanitarian board, not a multinational company. Again, farmers are intended to save seed; this will be crucial if the project is to succeed in reducing malnutrition.

Both these projects have been delayed by opposition from Greenpeace and other anti-GMO groups, which have used the courts and even vandalized fields. But they provide a model of how the message might get through that this technology can be used for environmentally beneficial, humanitarian purposes and should not be universally hated.

Mark Lynas is an author on environmental issues and a visiting fellow at Cornell University's College of Agriculture and Life Sciences.



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Upfront

KRISTIAN HAMMERSTAD

A Startup Has Trained Computers to Read Your Face. Now What?

A technology for reading emotions on faces can help companies sell candy. Its creators hope it can also take on bigger problems.

By David Talbot

Upfront

QUOTED

"They built the wrong factory for the wrong era and became roadkill."

– Frank Van Mierlo, CEO of 1366 Technologies, speaking of rival solar firms that spent too much too soon, whereas his company bided its time until the technology was ready.

Last year more than 1,000 people in four countries sat down and watched 115 television ads, such as one featuring anthropomorphized M&M candies boogying in a bar. All the while, webcams pointed at their faces and streamed images of their expressions to a server in Waltham, Massachusetts.

In Waltham, an algorithm developed by a startup company called Affectiva performed what is known as facial coding: it tracked the panelists' raised eyebrows, furrowed brows, smirks, half-smirks, frowns, and smiles. When this face data was later merged with real-world sales data, it turned out that the facial measurements could be used to predict with 75 percent accuracy whether sales of the advertised products would increase, decrease, or stay the same after the commercials aired. By comparison, surveys of panelists' feelings about the ads could predict the products' sales with 70 percent accuracy.

Although this was an incremental improvement statistically, it reflected a milestone in the field of affective computing. While people notoriously have a hard time articulating how they feel, now it is clear that machines can not only read some of their feelings but also go a step further and predict the statistical likelihood of later behavior.

Given that the market for TV ads in the United States alone exceeds $70 billion, insights from facial coding are "a big deal to business people," says Rosalind Picard, who heads the affective computing group at MIT's Media Lab and cofounded Affectiva; she left the company earlier this year but remains an investor.

Even so, facial coding has not yet delivered on the broader, more altruistic visions of its creators. Helping to sell more chocolate is great, but when will facial coding help people with autism read social cues, boost teachers' ability to see which students are struggling, or make computers empathetic?

Answers may start to come now that Affectiva has launched a software development kit that will let its platform be used for approved apps. The hope, says Rana el Kaliouby, the company's chief science officer and the other cofounder, is to spread the technology beyond marketing.

Applications such as educational assistance—informing teachers when students are confused, or helping autistic kids read emotions on other people's faces—figured strongly in the company's conception. Affectiva, which launched four years ago and now has 35 employees and $20 million in venture funding, grew out of the Picard lab's manifesto declaring that computers would do society a service if they could recognize and react to human emotions.

The system could pave the way for applications that read people's faces using home computers.

Affectiva's great hope is facial coding software called Affdex, which for now is mainly being used by market research companies. After spending three years convening webcam-based panels around the world, Affectiva has amassed a database of more than a billion facial reactions. The system could pave the way for applications that read the emotions on people's faces using ordinary home computers and portable devices. "Affectiva is tackling a hugely difficult problem, facial expression analysis in difficult and unconstrained environments, that a large portion of the academic community has been avoiding," says Tadas Baltrusaitis, a doctoral student at the University of Cambridge who has written several papers on facial coding.

Education may be ripe for the technology. A host of studies have shown the potential; one by researchers at the University of California, San Diego—who have founded a competing startup called Emotient—showed that facial expressions predicted the perceived difficulty of a video lecture and the student's preferred viewing speed. Another showed that facial coding could measure student engagement during an iPad-based tutoring session.

Such technologies may also be helpful to students with learning disabilities, says Winslow Burleson, an assistant professor at Arizona State University, author of a paper describing these potential uses of facial coding. Similarly, the technology could help clinicians tell whether patients understand instructions.

The coming year should reveal a great deal about whether facial coding can have benefits beyond TV commercials. Affdex faces competition from other startups, and even some marketers remain skeptical that facial coding is better than traditional methods of testing ads. Not all reactions are expressed on the face, and many other measurement tools claim to read people's emotions, says Ilya Vedrashko, who heads a consumer intelligence research group at Hill Holliday, an ad agency in Boston.

Yet el Kaliouby believes the technology is poised to take on bigger problems. "We want to make facial coding technology ubiquitous," she says.

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Upfront

100,000 The number of patients the U.K.'s National Health Service plans to have genetically sequenced by 2017.

New rock fracturing technology was tested in this geothermal well at the Newberry Volcano in Oregon.

Fracking Could Turn Out to Be Geothermal's Best Friend

A startup called AltaRock aims to turn a marginal power source into a carbon-free juggernaut.

By Kevin Bullis

The use of hydraulic fracturing has unlocked vast new reserves of natural gas. Now a Seattle-based startup named AltaRock is developing technology that might do the same for geothermal power.

Earlier this year near the Newberry Volcano in Oregon, AltaRock demonstrated a key part of that technology, a process akin to fracking. Just as fracking involves pumping liquid into underground shale formations under high pressure to unlock natural gas and oil trapped there, the new technology could unlock heat trapped deep underground.

Geothermal power plants now provide a tiny fraction of the world's energy needs. In the U.S., one of the world's biggest producers of geothermal energy, the total geothermal capacity is about 1 percent of the country's coal power capacity.

The problem is that conventional geothermal plants rely on a rare combination of geological features. Hot rock has to be accompanied by large amounts of hot water or steam that can easily be pumped to the surface. The rock formation needs to be porous so that the water can be continuously recirculated and reheated to keep a power plant running. Although such formations are rare, there's actually enough heat trapped under the United States within drilling distance (as deep as 10 kilometers) to supply its energy needs for thousands of years.

The trick is to pump cold water into rock in just the right way to make existing fractures expand and allow water to flow through. This method has been tried for decades, but it's been hard to get enough hot water flowing to justify the expense of drilling a well and building a power plant.

AltaRock's solution borrows a play from the natural gas industry involving fracturing rock at several points along a single well to reduce the number of wells needed. Companies do this by temporarily plugging up part of a well so that they can apply hydraulic pressure to one section, and then moving on to another part. It's long been known that doing the same thing could increase hot water production from a geothermal well, but geothermal wells are hotter, and they need to be engineered for higher amounts of water flow.

AltaRock has essentially invented a new plug. At a well near the Newberry Volcano, it has demonstrated that it's possible to temporarily plug a geothermal well with a special polymer. The material degrades after it's been down in the hot rock for a certain amount of time, allowing the company to move on to another part of the well. The company fractured three separate areas of one well using the technique. In a future commercial project, it might do seven or more per well, which "could dramatically lower the cost," says Susan Petty, the president and chief technology officer at AltaRock. She says the technology could be key to making geothermal energy competitive with coal.

There's enough heat trapped under the U.S. to supply its energy needs for thousands of years.

COURTESY OF NEWBERRY GEOTHERMAL EGS DEMONSTRATION

AI Startup Says It Has Defeated Captchas

By Rachel Metz

Captchas, those hard-to-read jumbles of letters and numbers that many websites use to foil spammers and automated bots, aren't necessarily impossible for computers to handle. An artificial-intelligence company called Vicarious says its technology can solve numerous types of Captchas more than 90 percent of the time.

It's not the first time that computer scientists have managed to fool this method of distinguishing man from machine. But Vicarious says its technique is more reliable and more useful than others because it doesn't require mountains of training data in order to recognize letters and numbers consistently. Nor does it take a lot of computing power.

Vicarious uses a visual perception system that can mimic the brain's ability to process visual information and recognize objects.

The purposes go well beyond Captchas: Vicarious hopes to eventually sell systems that can easily extract text and numbers from images (for instance, in Google's Street View maps), diagnose diseases by checking out medical images, or let you know how many calories you're about to eat by looking at your lunch.

"Anything people do with their eyes right now is something we aim to be able to automate," says cofounder D. Scott Phoenix.

Vicarious expands on an old idea of using an artificial neural network that is modeled on the brain and builds connections between artificial neurons. One big difference in Vicarious's approach, says cofounder Dileep George, is that its system can be trained with moving images rather than only static ones.

Vicarious set its cognition algorithms to work on solving Captchas as a way of testing its approach. Once trained to recognize numbers and letters, the system could solve Captchas from PayPal, Yahoo, Google, and other online services.

The company says its average accuracy rate ranges from 90 to 99 percent, depending on the type of Captcha (for example, some feature characters arranged within a grid of rectangles, while others might have characters in front of a wavy background). The system performed best with Captchas composed of letters that look as though they're made out of fingerprints.

"Captcha" stands for "completely automated public Turing test to tell computers and humans apart." The tests were created in 2000 by researchers at Carnegie Mellon University and are solved by millions of Web users daily.

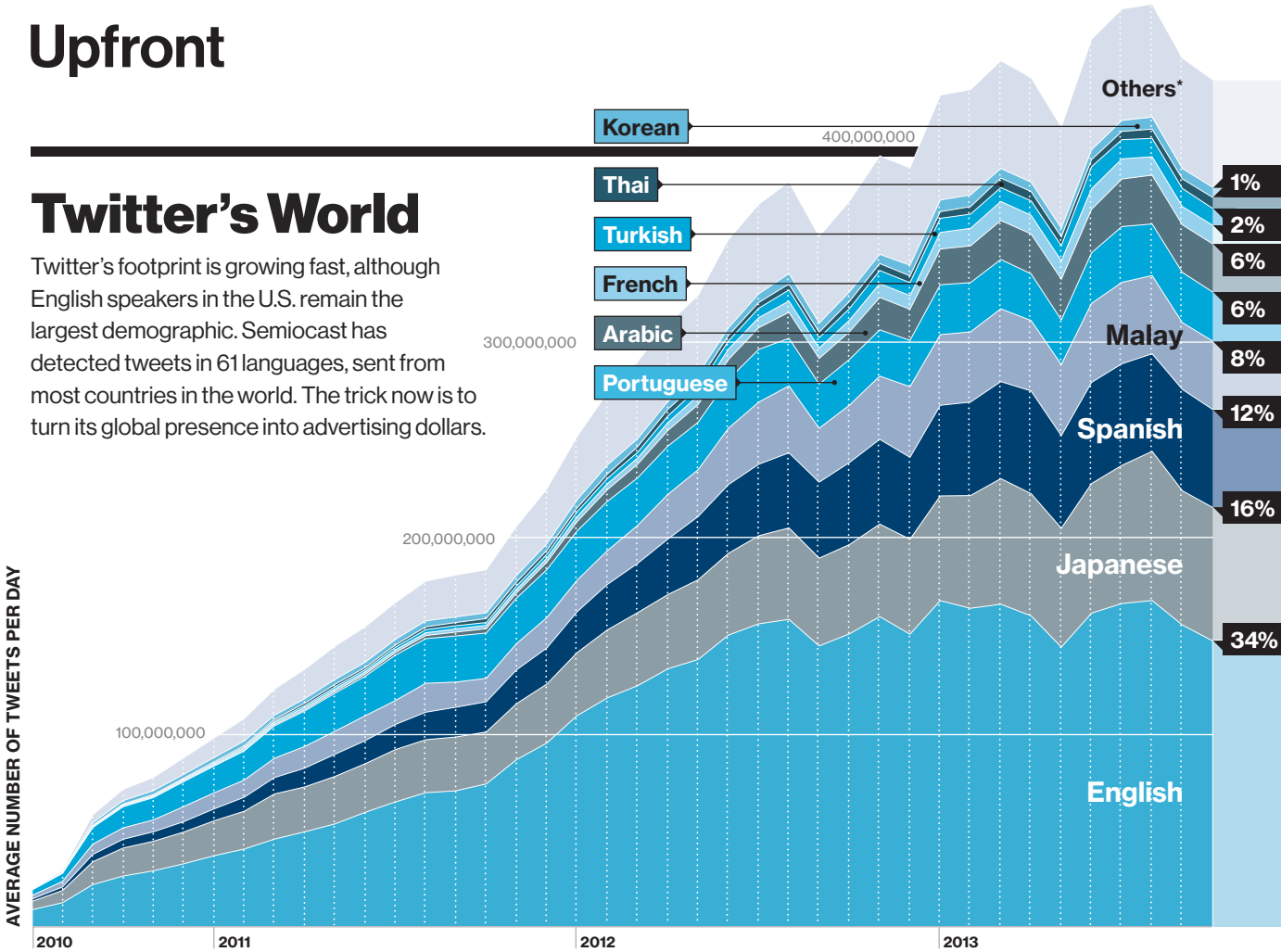
That's not about to change: Vicarious isn't going to release its system publicly. And besides, as Luis von Ahn, one of the creators of the Captcha, points out, many people have shown evidence of computerized Captcha-solving over the years. Von Ahn even helpfully passed along a link to a list of such instances.

ALEX ROBBINS

Upfront

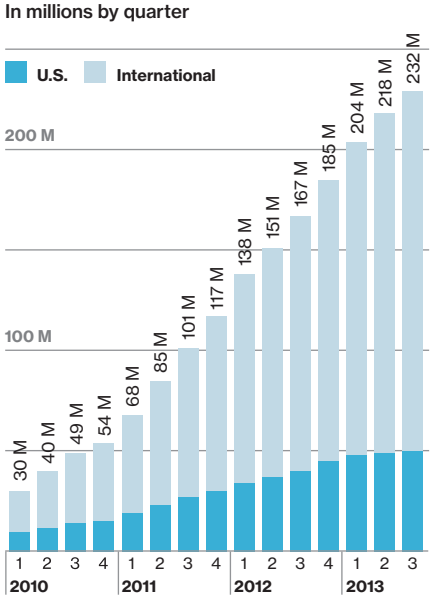
Twitter's World

Twitter's footprint is growing fast, although English speakers in the U.S. remain the largest demographic. Semiocast has detected tweets in 61 languages, sent from most countries in the world. The trick now is to turn its global presence into advertising dollars.



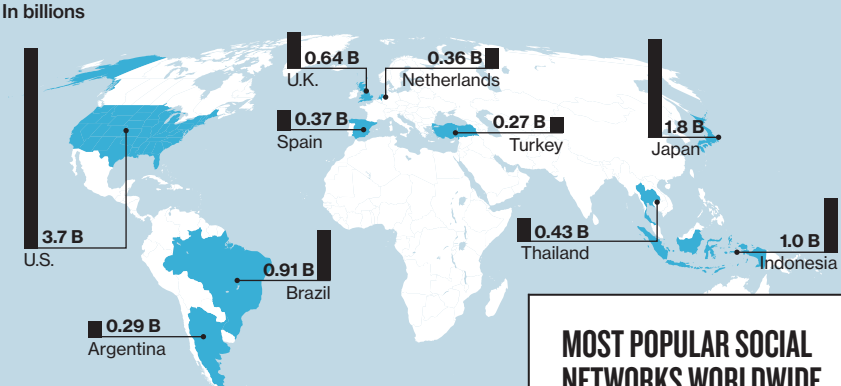
ACTIVE TWITTER USERS WORLDWIDE

In millions by quarter



TOP 10 COUNTRIES BY TWEETS IN JUNE 2013

In billions



AD REVENUE PER THOUSAND TIMELINE VIEWS

July 1, 2013–September 30, 2013

U.S.	International
$2.58	$0.36

MOST POPULAR SOCIAL NETWORKS WORLDWIDE

By percentage of Internet users†

Facebook	51%
Google+	26%
YouTube	25%
Twitter	22%
Sina Weibo	21%

ILLUSTRATION BY WALTER BAUMANN. DATA: SEMIOCAST (LANGUAGES AND TWEETS BY COUNTRY, FROM A 10 PERCENT SAMPLE); TWITTER (MONTHLY ACTIVE USERS AND AD REVENUE); AND EMARKETER (NETWORK RANKINGS). *EACH "OTHER" LANGUAGE IS LESS THAN 1 PERCENT. †BASED ON INTERNET USERS AGED 16–64 WHO USED A NETWORK IN THE MONTH PRECEDING APRIL 26, 2013.

Average download speed of AT&T's LTE network, currently considered the fastest in the U.S. **16** megabits per second

60 megabits per second Download speed Sprint says its tri-band cellular network technology will make possible.

Startup Offers a Curious Twist on Biomanufacturing

We already know how to reëngineer organisms so they'll make useful chemicals. What if you could get the same results without the living cell?

By Susan Young

Biotechnologists have genetically engineered bacteria and other microbes to produce biofuels and chemicals from renewable resources. The problem is that the complex metabolic pathways in these living organisms can be difficult to control, and the desired products can be toxic to the microbes, which means the microbes may produce only tiny amounts of the chemicals they were designed to make. Living microbes also have to spend cellular resources on the metabolic processes that keep them alive, which of course means those resources aren't being used to produce chemicals. What if you could take the living cell out of the equation?

That's the approach taken by Greenlight Biosciences, a Boston-area startup, which engineers microbes to make various enzymes that can produce chemicals and then breaks open the bugs to harvest the enzymes. The idea is that you could get the same benefits of the reëngineered microörganisms without having to keep them alive in order to continue doing the job. The scientists don't have to go to the trouble of isolating the enzymes from the other cellular material; instead, they add chemicals to inhibit unwanted biochemical reactions. By mixing slurries based on different microbes with sugars and other carbon-based feedstocks, the company can generate complex reactions to produce a variety of chemicals. Greenlight says its technology allows it to make cheaper versions of existing chemicals and has already produced a food additive, drug products, and pesticides.

The idea is to get the same benefits of reëngineered microörganisms without having to keep them alive.

The biggest motivation in starting the company was to figure out how to produce such compounds in a more environmentally friendly way, says CEO Andrey Zarur. But Greenlight's products also have to be cheaper than those produced by chemical- or cell-based manufacturing, he says, or industries will be reluctant to use them.

Greenlight's strategy is a departure from classic fermentation processes that depend on vats of living microbes. Several companies are engineering bacteria and yeast to produce specialty chemicals, but for the most part, these groups keep the bugs alive. Amyris, for example, can make biofuels, medicines, and chemicals used in cosmetics and lubricants by engineering microbes with new sets of enzymes that can modify sugars and other starting materials. Metabolix has engineered bacteria to produce biodegradable plastic.

A problem with that strategy is that when bacteria and other microbes are turned into living chemical factories, they still have to put some resources into growing instead of chemical production. Furthermore, even in a seemingly simple bacterium, metabolism is complicated.

"Metabolic pathways have complex regulation within them and across them," says Mark Styczynski, a metabolic engineer and systems biologist at the Georgia Institute of Technology. Changing one metabolic pathway to improve chemical production can sometimes have negative consequences for the rest of the cell.

Thus, separating the production pathway from the needs of the cell could be

TO MARKET

Simple Smart Watch

Toq

COMPANY:
Qualcomm

PRICE:
$300

AVAILABILITY:
Now

Much of the Toq's appeal comes from its simplicity. It provides a way for important notifications to flow from your smartphone to your wrist, where you can take them in at a glance and quickly dismiss or act upon them. Unlike some other smart watches, the Toq also lasts days between charges, thanks to the novel Mirasol display technology. The

device can be paired with any Android smartphone, and you can then choose which of the apps on your phone will send notifications to your wrist. The Toq doesn't let you talk into your wrist like Dick Tracy. But it does notify you of an incoming call. With a single tap you can decline a call or accept it, at which point you need to grab your handset to start talking.

TOM SIMONITE/MIT TECHNOLOGY REVIEW

Upfront

17,000 The number of mobile malware samples collected by McAfee Labs in the first half of this year.

a huge advantage, he says. In Greenlight's lab, researchers use bubbling bioreactors to grow bacteria in liquid culture, maintaining different species and strains that can produce a variety of enzymes.

Once the bugs have reached a certain density, the researchers send them through a high-pressure extruder to break them into pieces. Then they add drugs to the resulting slurry to turn off most of the cells' metabolic enzymes; the useful enzymes are unaffected because they have been engineered to resist the drugs.

The technology that keeps the exposed metabolic pathways working was developed by James Swartz, a biochemical engineer at Stanford University who left his position as a protein engineer at the biotechnology company Genentech to develop cell-free methods for producing pharmacological proteins. Seeking more control over the biological machinery that produces proteins, Swartz figured out how to give that machinery the biochemical environment it needed even outside its normal home in a cell. Not only did his methods enable him to make more complex proteins, but they could also be used to control biological machinery to make small molecules and chemicals. "We've found that by reproducing the chemical conditions that occur inside the cell," he says, "we activate a lot of metabolic processes, even ones people thought were too complicated."

"We activate a lot of metabolic processes, even ones people thought were too complicated."

REVIEW

Fitness Trackers Still Need to Work Out a Few Kinks

These activity-tracking wristbands prod you to get more exercise. But IT editor Rachel Metz finds them to be a work in progress.

Jawbone Up 24 ($150)
My favorite of the three, the Up 24 blends function and style. Beyond being the most fashionable of the trackers I tried, it was the most full-featured and had the most user-friendly app. The single button on one end of the band shows you how much power the device has and lets it start or stop tracking your sleep. One of its best features is its "smart alarm," which wakes you with gentle vibration when you're in a state of light sleep, up to 30 minutes before your planned wakeup time. The app also lets you log the meals you've eaten—you can use your phone to scan bar codes on food packages—and it can draw in data from other fitness apps, like RunKeeper and Strava. Most impressive, you can use the device to automate reactions to specific triggers. I set the Up 24 to turn on an Internet-connected desk lamp every time I woke up.

Fitbit Force ($130)
The Fitbit Force looks the most like a digital watch (the time even shows up on the display by default), which may ease your transition to wearing a fitness tracker all day. I liked its crisp, bright, slightly angled OLED display, which juts out of its band and has a side button that you can use to cycle through its data fields, including time, steps taken, distance traveled, and calories burned. Its app presents lots of information at a glance. A page for each day shows measurements like steps taken, miles walked, and weight to lose until you hit a goal, and these are easy to hide if you don't care about certain metrics. Its wristband was the most comfortable, since it's fully adjustable. But a removable piece of plastic secures the band to your arm, making it a pain to put on and leaving me constantly worried that I would lose this specialized little part.

Nike+ FuelBand SE ($149)
This band sets itself apart with its focus on competition, from the virtual trophies you can reap for meeting certain activity goals to the way it encourages users to "win" hours (defined by five minutes of activity per hour). The FuelBand SE also has its own system of points you earn from activity, illustrated on the wristband with a rainbow row of LEDs that gradually change from red to green throughout the day. I liked this because it helped me think less about the specifics of movement and more about being active in general. The bracelet looks sportier than its peers, with a stiff-framed, rounded, rubbery body and a strong clasp that opens with the push of a tiny button and closes with a satisfying click. However, this hard body made it feel like a court-ordered monitoring bracelet (not that I know from personal experience).

COURTESY OF JAWBONE. COURTESY OF FITBIT. COURTESY OF NIKE

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Upfront

QUOTED

"All this information is hiding in plain sight on store shelves."

– Premise cofounder David Soloff, whose company offers a mobile app that crowdsources the price of key products in cities around the globe every day.

The Secret Inside the New iPad

The inclusion of indium gallium zinc oxide transistors in iPads shows that the display industry is poised to begin churning out a new breed of high-performance screens.

By Mike Orcutt

One of the most important innovations in Apple's latest iPads lies behind the screen. In some of the tablets, the pixels in the display are controlled by transistors made of a material called indium gallium zinc oxide (IGZO), a promising replacement for the conventional amorphous silicon.

Displays featuring "backplanes" of IGZO transistors should make it possible for tablets and TVs to have much higher-resolution displays while consuming significantly less power. The technology has already cropped up in a few high-end smartphones and televisions, but its inclusion in iPads suggests we can expect IGZO to improve several more popular products over the next year.

Display makers are racing to produce screens with ever-higher resolution, including ones based on organic light-emitting diodes (OLEDs), which promise not only a better picture but also greater power efficiency and compatibility with flexible form factors. But the display makers have run up against the physical limits of amorphous silicon. If transistors can be made from a material with a higher degree of "electron mobility," they can be smaller, making it possible to pack more pixels into a given space.

The highest-resolution smartphone screens already feature an alternative material called low-temperature polysilicon (LTPS). But LTPS panels are expensive to make, and the fabrication method has proved difficult to adapt to displays larger than those on phones.

The new iPad Air uses 57 percent less power for its display than previous generations of iPads.

Not all of the latest iPads have IGZO displays; in fact, it's not entirely clear how many of the tablets have the technology. Luke Koo, senior manager of a team in Seoul that tears down devices for the IHS research firm, says IGZO-based displays made by Sharp are in at least some iPad Minis. Jennifer Colgrove, the lead analyst at Touch Display Research, also says Sharp is supplying IGZO displays for Apple tablets, but she is unsure whether they are in the Mini, the larger iPad Air, or both. Another Apple supplier, LG Display, can now mass-produce IGZO panels and is making them for its 55-inch OLED TV, Colgrove says.

By analyzing the power consumption of the iPad Air, Raymond Soneira, the founder of DisplayMate Technologies, found something unusual: its display uses 57 percent less power than the ones in previous generation of iPads. That tells him the display "simply can't be amorphous silicon," though it's possible it uses not IGZO but LTPS.

Apple would not comment, but no matter how extensively the iPads are using IGZO, it's clear the technology is finally gaining momentum after years of manufacturing challenges.

TO MARKET

A Robot with Legs

UBR1

COMPANY:
Unbounded Robotics

PRICE:
$35,000

AVAILABILITY:
Summer 2014

COURTESY OF PREMISE. COURTESY OF UNBOUNDED ROBOTICS

Robots have long been a part of manufacturing, but they have traditionally worked in isolation. This is now starting to change, and UBR1, from Unbounded Robotics, is the first mobile robot able to work alongside humans. Melonee Wise, CEO and cofounder of the company, expects to see businesses putting UBR1 to work within the next few years at tasks such as stocking shelves in warehouses. UBR1 has a 75-centimeter arm with four joints and a pincer grip, and it moves on a wheeled base. The robot has features that make it safe to work around; if it has accidentally shoved a person or invaded someone's space, its arm can be pushed aside. "This is the Model T of robots," Wise says.

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*Reference: Schneider Electric White Paper #52 (assuming 40 employees)

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Q+A

Danah Boyd

Kids today! They're online all the time, sharing every little aspect of their lives. *What's wrong with them?* Actually, nothing, says Danah Boyd, a Microsoft researcher who studies social media. In a book coming out this winter, *It's Complicated: The Social Lives of Networked Teens*, Boyd argues that teenagers aren't doing much online that's very different from what kids did at the sock hop, the roller rink, or the mall. They do so much socializing online mostly because they have little choice, Boyd says: parents now generally consider it unsafe to let kids roam their neighborhoods unsupervised. Boyd, 36, spoke with *MIT Technology Review*'s deputy editor, Brian Bergstein, at Microsoft Research's offices in Manhattan.

I feel like you might have titled the book *Everybody Should Stop Freaking Out.*
It's funny, because one of the early titles was *Like, Duh*. Because whenever I would show my research to young people, they'd say, "Like, duh. Isn't this so obvious?" And it opens with the anecdote of a boy who says, "Can you just talk to my mom? Can you tell her that I'm going to be okay?" I found that refrain so common among young people.

You and your colleague Alice Marwick interviewed 166 teenagers for this book. But you've studied social media for a long time. What surprised you?
It was shocking how heavily constrained their mobility was. I had known it had gotten worse since I was a teenager, but I didn't get it—the total lack of freedom to just go out and wander. Young people weren't even trying to sneak out [of the house at night]. They were trying to get online, because that's the place where they hung out with their friends.

And I had assumed based on the narratives in the media that bullying was on the rise. I was shocked that data showed otherwise.

Then why do narratives such as "Bullying is more common online" take hold?
It's made more visible. There is some awful stuff out there, but it frustrates me when a panic distracts us from the reality of what's going on. One of my frustrations is that there are some massive mental health issues, and we want to blame the technology [that brings them to light] instead of actually dealing with mental health issues.

I take your point that Facebook or Instagram is the equivalent of yesterday's hangouts. But social media amplify everyday situations in difficult new ways. For example, kids might instantly see on Facebook that they're missing out on something other kids are doing together.
That can be a blessing or a curse. These interpersonal conflicts ramp up much faster [and] can be much more hurtful. That's one of the challenges for this cohort of youth: some of them have the social and emotional skills that are necessary to deal with these conflicts; others don't. It really sucks when you realize that somebody doesn't like you as much as you like them. Part of it is, then, how do you use that as an opportunity not to just wallow in your self-pity but to figure out how to interact and be like "Hey, let's talk through what this friendship is like"?

You contend that teenagers are not cavalier about privacy, despite appearances, and adeptly shift sensitive conversations into chat and other private channels.
Many adults assume teens don't care about privacy because they're so willing to participate in social media. They want to be in public. But that doesn't mean that they want to *be* public. There's a big difference. Privacy isn't about being isolated from others. It's about having the capacity to control a social situation.

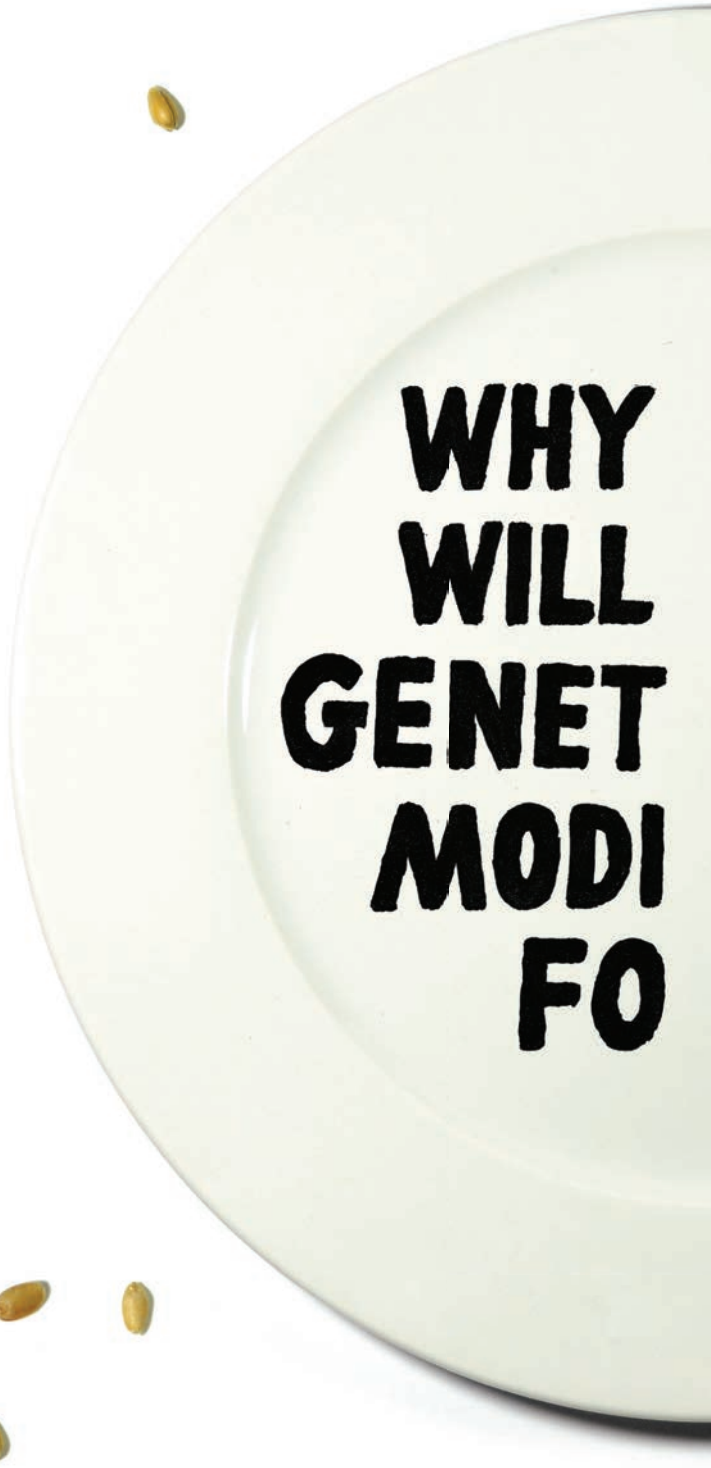
So if parents can let go of some common fears, what should they be doing?
One thing that I think is dangerous is that we're trained that we are the experts at everything that goes on in our lives and our kids' lives. So the assumption is that we should teach them by telling them. But I think the best way to teach is by asking questions: "Why are you posting that? Help me understand." Using it as an opportunity to talk. Obviously there comes a point when your teenage child is going to roll their eyes and go, "I am not interested in explaining anything more to you, Dad."

The other thing is being present. The hardest thing that I saw, overwhelmingly—the most unhealthy environments—were those where the parents were not present. They could be physically present and not actually present.

What will today's teenagers worry about with their kids?
The core concerns tend not to change: sexuality and the display of sexuality. For me it was leather miniskirts, and the ridiculous bangs, and fishnets, and bras on top of your shirts—gasp! Today it's sexting and selfies. And pressures for freedom: over generations we keep finding new ways to constrain and control, and technologies provide a relief valve or a way of getting around them. All of a sudden there's a new form of freedom. T

DANA SMITH

Climate change will make it increasingly difficult to feed the world.



Signs of late blight appear suddenly but predictably in Ireland as soon as the summer weather turns humid, spores of the funguslike plant pathogen wafting across the open green fields and landing on the wet leaves of the potato plants. This year it began to rain in early August. Within several weeks, late blight had attacked a small plot of potatoes in the corner of the neat grid of test plantings at the headquarters of Teagasc, Ireland's agricultural agency, in Carlow.

It's now more than a month after the potato plants were first struck and still a few weeks before the crop will be harvested. A large country house, housing the operations of Teagasc, overlooks the field trials, and well-dressed Irish and EU bureaucrats hustle in and out. Much of the sprawling building was constructed in the 1800s, during the worst of the famines that were triggered when blight devastated Ireland's potato harvest. Such famines

Illustrations by Alex Robbins

MIT TECHNOLOGY REVIEW
VOL. 117 | NO. 1

By David Rotman

Biotech crops will have an essential role in ensuring that there's enough to eat.

are far in the past, but the plant disease remains a costly torment to the country's farmers, requiring them to douse their crops frequently with fungicides. As part of an EU-wide project called Amiga to study the impact of genetically modified (GM) plants, Teagasc researcher Ewen Mullins is testing potatoes that are engineered to resist blight.

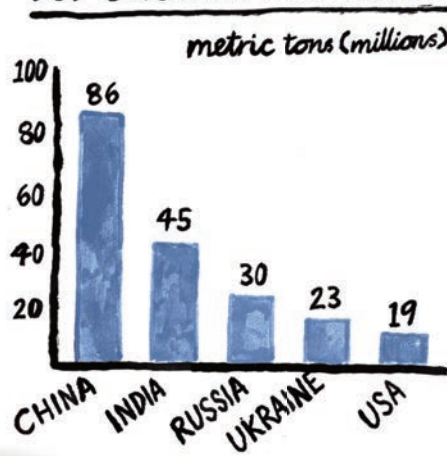
It's breezy, and though the summer is over, it's still warm and humid. "Perfect weather for blight," says Mullins. Bending over the conventionally bred plants, he firmly pulls back the wilted stems and leaves to show that the tubers, half-exposed in the ground, are scarred with black blotches. Then he picks at a green leaf from one of the genetically engineered plants, which have been modified with a blight-resistant gene from a wild potato that grows in South America. The defenses of the potato plant have fought off the spores, rendering them harmless. The plant, says Mullins simply, "has performed well."

It's the second year of what are scheduled to be three-year field trials. But even if the results from next year are similarly

POTATO

POTATOES ARE A KEY STAPLE FOR MILLIONS OF PEOPLE AROUND THE WORLD AND AN INCREASINGLY POPULAR CROP IN POOR REGIONS

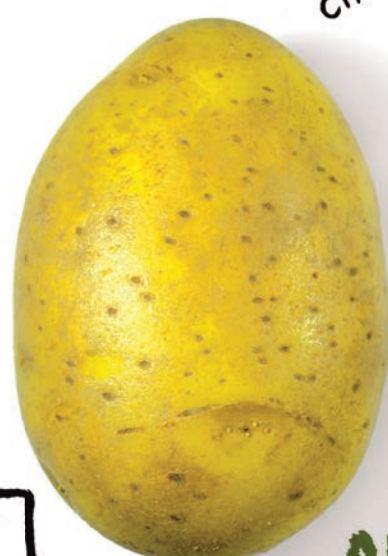
TOP GROWING COUNTRIES (2012)



TRANSGENIC POTATOES

863 The number of U.S. permits and notifications for testing since 1985

0 The number of commercial varieties



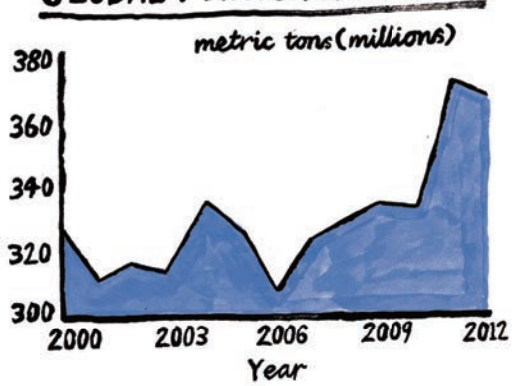
$6.2 BILLION

The annual cost of damage and controls associated with late blight. $1 billion is spent on fungicides alone.

POTENTIAL TRAITS:
Blight resistance, reduced degradation during storage, reduced bruising

LATE BLIGHT IS AN OOMYCETE, A TYPE OF WATER MOLD

GLOBAL POTATO PRODUCTION



CLIMATE CHANGE BOTTOM LINE

Potatoes are vulnerable to high temperatures. Hotter days and higher humidity could increase the risk of late blight in some areas.

DATA FROM USDA, UNITED NATIONS, *NATURE*

encouraging, Teagasc has no intention of giving farmers access to the plant, which was developed by researchers at Wageningen University in the Netherlands. Such genetically engineered crops remain controversial in Europe, and only two are approved for planting in the EU. Though Mullins and his colleagues are eager to learn how blight affects the GM potatoes and whether the plants will affect soil microbes, distributing the modified plant in Ireland is, at least for now, a nonstarter.

Nevertheless, the fields of Carlow present a tantalizing picture of how genetically modified crops could help protect the world's food supply. Blight-resistant potatoes would be one of the first major foods genetically engineered to incorporate defenses against plant diseases, which annually destroy some 15 percent of the world's agricultural harvest. Despite the heavy use of fungicides, late blight and other plant diseases ruin an estimated fifth of the world's potatoes, a food increasingly grown in China and India. Stem rust, a fungal disease of wheat, has spread through much of Africa and the Arabian Peninsula and is now threatening the vast growing regions of central and south Asia, which produce some 20 percent of the world's wheat. Bananas, which are a primary source of food in countries such as Uganda, are often destroyed by wilt disease. In all these cases, genetic engineering has the potential to create varieties that are far better able to withstand the onslaught.

GM potatoes could also lead to a new generation of biotech foods sold directly to consumers. Though transgenic corn, soybeans, and cotton—mostly engineered to resist insects and herbicides—have been widely planted since the late 1990s in the United States and in a smattering of other large agricultural countries, including Brazil and Canada, the corn and soybean crops go mainly into animal feed, biofuels, and cooking oils. No genetically modified varieties of rice, wheat, or potatoes are widely grown, because opposition to such foods has discouraged investment in developing them and because seed companies haven't found ways to make the kind of money on those crops that they do from genetically modified corn and soybeans.

With the global population expected to reach more than nine billion by 2050, however, the world might soon be hungry for such varieties. Although agricultural productivity has improved dramatically over the past 50 years, economists fear that these improvements have begun to wane at a time when food demand, driven by the larger number of people and the growing appetites of wealthier populations, is expected to rise between 70 and 100 percent by midcentury. In particular, the rapid increases in rice and wheat yields that helped feed the world for decades are showing signs of slowing down, and production of cereals will need to more than double by 2050 to keep up. If the trend continues, production might be insufficient to meet demand unless we start using significantly more land, fertilizer, and water.

Climate change is likely to make the problem far worse, bringing higher temperatures and, in many regions, wetter conditions that spread infestations of disease and insects into new areas. Drought, damaging storms, and very hot days are already taking a toll on crop yields, and the frequency of these events is expected to increase sharply as the climate warms. For farmers, the effects of climate change can be simply put: the weather has become far more unpredictable, and extreme weather has become far more common.

The central highlands of Mexico, for example, experienced their driest and wettest years on record back to back in 2011 and 2012, says Matthew Reynolds, a wheat physiologist at the International Maize and Wheat Improvement Center in El Batán. Such variation is "worrisome and very bad for agriculture," he says. "It's extremely challenging to breed for it. If you have a relatively stable climate, you can breed crops with genetic characteristics that follow a certain profile of temperatures and rainfall. As soon as you get into a state of flux, it's much more difficult to know what traits to target."

One advantage of using genetic engineering to help crops adapt to these sudden changes is that new varieties can be created quickly. Creating a potato variety through conventional breeding, for example, takes at least 15 years; producing a genetically modified one takes less than six months. Genetic modification also allows plant breeders to make more precise changes and draw from a far greater variety of genes, gleaned from the plants' wild relatives or from different types of organisms. Plant scientists are careful to note that no magical gene can be inserted into a crop to make it drought tolerant or to increase its yield—even resistance to a disease typically requires multiple genetic changes. But many of them say genetic engineering is a versatile and essential technique.

Drought, damaging storms, and very hot days are already taking a toll on crop yields.

"It's an overwhelmingly logical thing to do," says Jonathan Jones, a scientist at the Sainsbury Laboratory in the U.K. and one of the world's leading experts on plant diseases. The upcoming pressures on agricultural production, he says, "[are] real and will affect millions of people in poor countries." He adds that it would be "perverse to spurn using genetic modification as a tool."

It's a view that is widely shared by those responsible for developing tomorrow's crop varieties. At the current level of agricultural production, there's enough food to feed the world, says Eduardo Blumwald, a plant scientist at the University of California, Davis. But "when the population reaches nine billion?" he says. "No way, José."

FAILED PROMISES

The promise that genetically modified crops could help feed the world is at least as old as the commercialization of the first transgenic seeds in the mid-1990s. The corporations that helped turn genetically engineered crops into a multibillion-dollar business, including the large chemical companies Monsanto, Bayer, and DuPont, promoted the technology as part of a life science revolution that would

greatly increase food production. So far it's turned out, for a number of reasons, to have been a somewhat empty promise.

To be sure, bioengineered crops are a huge commercial success in some countries. The idea is simple but compelling: by inserting a foreign gene derived from, say, bacteria into corn, you can give the plant a trait it wouldn't otherwise possess. Surveys estimate that more than 170 million hectares of such transgenic crops are grown worldwide. In the United States, the majority of corn, soybeans, and cotton planted have been engineered with a gene from the soil bacterium *Bacillus thuringensis*—Bt—to ward off insects or with another bacterial gene to withstand herbicides. Worldwide, 81 percent of the soybeans and 35 percent of the corn grown are biotech varieties. In India, Bt cotton was approved more than a decade ago and now represents 96 percent of the cotton grown in the country.

Yet it's not clear whether that boom in transgenic crops has led to increased food production or lower prices for consumers. Take corn, for example. In the United States, 76 percent of the crop is genetically modified to resist insects, and 85 percent can tolerate being sprayed with a weed killer. Such corn has, arguably, been a boon to farmers, reducing pesticide use and boosting yields. But little of U.S. corn production is used directly for human food; about 4 percent goes into high-fructose corn syrup and 1.8 percent to cereal and other foods. Genetically modified corn and soybeans are so profitable that U.S. farmers have begun substituting them for wheat: around 56 million acres of wheat were planted in 2012, down from 62 million in 2000. As supply fell, the price of a bushel of wheat rose to nearly $8 in 2012, from $2.50 in 2000.

Only a handful of large companies can afford the risk and expense of commercializing GMOs.

So far, the short list of transgenic crops used directly for food includes virus-resistant papaya grown in Hawaii, Bt sweet corn recently commercialized in the United States by Monsanto, and a few varieties of squash that resist plant viruses. That list could be about to grow, however. The Indonesian agricultural agency expects to approve a blight-resistant potato soon, and J. R. Simplot, an agricultural supplier based in Boise, Idaho, is hoping to commercialize its own version by 2017. Monsanto, which abandoned an attempt to develop GM wheat in 2004, bought a wheat-seed company in 2009 and is now trying again. And Cornell researchers are working with collaborators in India, Bangladesh, and the Philippines, countries where eggplant is a staple, to make an insect-resistant form of the vegetable available to farmers.

These bioengineered versions of some of the world's most important food crops could help fulfill initial hopes for genetically modified organisms, or GMOs. But they will also almost certainly heat up the debate over the technology. Opponents worry that inserting foreign genes into crops could make food dangerous or allergenic, though more than 15 years of experience with transgenic crops have revealed no health dangers, and neither have a series of scientific studies. More credibly, detractors suggest that the technology is a ploy by giant corporations, particularly Monsanto, to peddle more herbicides, dominate the agricultural supply chain, and leave farmers dependent on high-priced transgenic seeds. The most persuasive criticism, however, may simply be that existing transgenic crops have done little to guarantee the future of the world's food supply in the face of climate change and a growing population.

The first generation of insect-resistant and herbicide-tolerant crops offer few new traits, such as drought tolerance and disease resistance, that could help the plants adapt to changes in weather and disease patterns, acknowledges Margaret Smith, a professor of plant breeding and genetics at Cornell University. Nonetheless, she says there is no valid reason to dismiss the technology as plant scientists race to increase crop productivity. Scientists are "facing a daunting breeding challenge," Smith says. "We will need a second generation of transgenic crops. It would be a mistake to rule out this tool because the first products didn't address the big issues."

Developing crops that are better able to withstand climate change won't be easy. It will require plant scientists to engineer complex traits involving multiple genes. Durable disease resistance typically requires a series of genetic changes and detailed knowledge of how pathogens attack the plant. Traits such as tolerance to drought and heat are even harder, since they can require basic changes to the plant's physiology.

Is genetic engineering up to the task? No one knows. But recent genomic breakthroughs are encouraging. Scientists have sequenced the genomes of crops such as rice, potatoes, bananas, and wheat. At the same time, advances in molecular biology mean that genes can be deleted, modified, and inserted with far greater precision. In particular, new genome engineering tools known as Talens and Crispr allow geneticists to "edit" plant DNA, changing chromosomes exactly where they want.

EXACT EDITS

The workshop adjacent to the rows of greenhouses at the edge of Cornell's campus in Ithaca, New York, smells musty and damp from the crates of potatoes. It is less than a mile from the university's molecular biology labs, but what you see are wooden conveyer belts, wire screens, and water hoses. Walter De Jong is sorting and sizing harvested potatoes as part of a multiyear effort to come up with yet a better variety for the region's growers. Boxes are filled with potatoes—some small and round, others large and misshapen. Asked what traits are important to consumers, he smiles slyly and says, "Looks, looks, looks."

The question of how he feels about efforts to develop transgenic potatoes is not as easily answered. It's not that De Jong is opposed to genetic engineering. As a potato breeder, he's well versed in conventional methods of introducing new traits, but he also has a PhD in plant pathology and has done considerable research in molecular biology; he knows the opportunities that

advanced genetics opens up. In the northeastern United States, a variety of potato is optimized for about a 500-mile radius, taking into account the length of the growing season and the type of weather in the area. Climate change means these growing zones are shifting, making crop breeding like solving a puzzle in which the pieces are moving around. The speed offered by genetic modification would help. But, De Jong says dismissively, "I don't expect to use [transgenic] technology. I can't afford it."

"It's a curious situation," he says. Scientists at public and academic research institutions have done much of the work to identify genes and understand how they can affect traits in plants. But the lengthy testing and regulatory processes for genetically modified crops, and the danger that consumers will reject them, mean that only "a handful of large companies" can afford the expense and risk of developing them, he says.

But De Jong suddenly becomes animated when he's asked about the newest genome engineering tools. "This is what I have been waiting my whole career for," he says, throwing his hands up. "As long as I have been a potato scientist, I've wanted two things: a sequenced potato genome and the ability to modify the genome at will." Across campus, De Jong also runs a molecular biology lab, where he has identified the DNA sequence responsible for red pigment in potato tubers. Soon, it could be possible to precisely alter that sequence in a potato cell that can then be grown into a plant: "If I had a white potato I wanted to turn red, I could just edit one or two nucleotides and get the color I want." Plant breeding "is not the art of shuffling genes around," De Jong explains. "Basically, all potatoes have the same genes; what they have is different versions of the genes—alleles. And alleles differ from one another in a few nucleotides. If I can edit the few nucleotides, why breed for [a trait]? It's been the holy grail in plant genetics for a long time."

One problem with conventional genetic engineering techniques is that they add genes unpredictably. The desired gene is inserted into the targeted cell in a petri dish using either a plant bacterium or a "gene gun" that physically shoots a tiny particle covered with the DNA. Once the molecules are in the cell, the new gene is inserted into the chromosome randomly. (The transformed cell is grown in a tissue culture to become a plantlet and eventually a plant.) It's impossible to control just where the gene gets added; sometimes it ends up in a spot where it can be expressed effectively, and sometimes it doesn't. What if you could precisely target spots on the plant's chromosome and add new genes exactly where you want them, "knock out" existing ones, or modify genes by switching a few specific nucleotides? The new tools allow scientists to do just that.

Talens, one of the most promising of these genome engineering tools, was inspired by a mechanism used by a bacterium that infects plants. Plant pathologists identified the proteins that enable the bacterium to pinpoint the target plant DNA and found ways to engineer these proteins to recognize any desired sequence; then they fused these proteins with nucleases that cut DNA, creating a precise "editing" tool. A plant bacterium or gene gun is used to get the tool into the plant cell; once inside, the proteins zero in on a specific DNA sequence. The proteins deliver the nucleases to an exact spot on the chromosome, where they cleave the plant's DNA. Repair of the broken chromosome allows new genes to be inserted or other types of modifications to be made. Crispr, an even newer version of the technology, uses RNA to zero in on the targeted genes. With both Talens and Crispr, molecular biologists can modify even a few nucleotides or insert and delete a gene exactly where they want on the chromosome, making the change far more predictable and effective.

Cultivation of GM potatoes at Teagasc begins with a GM plantlet grown in a tissue culture (1); it is transferred to a greenhouse (2) and eventually to field trials (3). The harvested tubers appear healthy and free of blight (4).

COURTESY OF TEAGASC

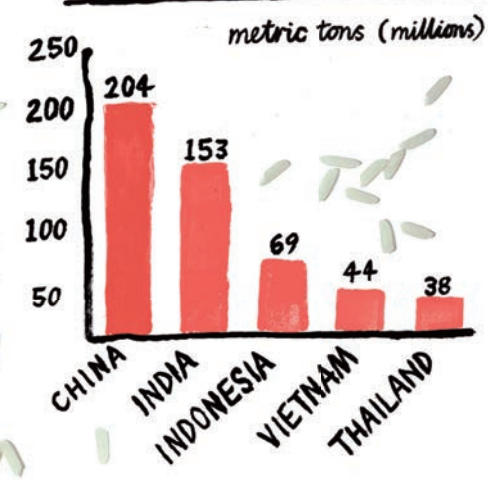
One implication of the new tools is that plants can be genetically modified without the addition of foreign genes. Though it's too early to tell whether that will change the public debate over GMOs, regulatory agencies—at least in the United States—indicate that crops modified without foreign genes won't have to be scrutinized as thoroughly as transgenic crops. That could greatly reduce the time and expense it takes to commercialize new varieties of genetically engineered foods. And it's possible that critics of biotechnology could draw a similar distinction, tolerating genetically modified crops so long as they are not transgenic.

Dan Voytas, director of the genome engineering center at the University of Minnesota and one of Talens's inventors, says one of his main motivations is the need to feed another two billion people by the middle of the century. In one of his most ambitious efforts, centered at the International Rice Research Institute in Los Baños, the Philippines, he is collaborating with a worldwide

RICE

MORE THAN 90 PERCENT OF RICE IS GROWN IN ASIA, BUT IT IS A STAPLE FOR NEARLY HALF THE PEOPLE IN THE WORLD.

TOP GROWING COUNTRIES (2012)



TRANSGENIC RICE

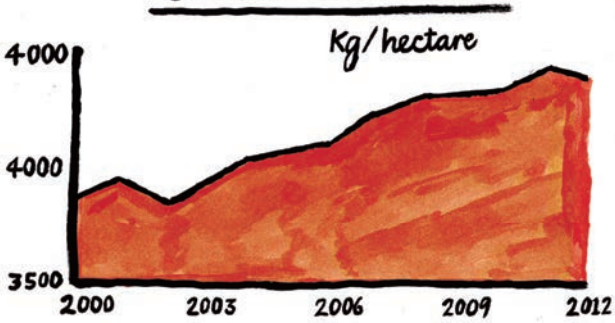
286 The number of U.S. permits and notifications for testing since 1985

0 The number of commercial varieties

Rice yields range from less than 1 ton per hectare to more than 10 tons per hectare in temperate, irrigated systems.

POTENTIAL TRAITS:
Drought tolerance, submergence tolerance, heat tolerance, salt tolerance

GLOBAL RICE YIELD



CLIMATE CHANGE BOTTOM LINE

Though it thrives in hot and wet conditions, rice is vulnerable to heat stress, rising seawater, and uncontrolled flooding.

DATA FROM USDA, UN, INTERNATIONAL RICE RESEARCH INSTITUTE

network of researchers to rewrite the physiology of rice. Rice and wheat, like other grains, have what botanists call C_3 photosynthesis, rather than the more complex C_4 version that corn and sugarcane have. The C_4 version of photosynthesis uses water and carbon dioxide far more efficiently. If the project is successful, both rice and wheat yields could be increased in regions that are becoming hotter and drier as a result of climate change.

Rewriting the core workings of a plant is not a trivial task. But Voytas says Talens could be a valuable tool—both to identify the genetic pathways that might be tweaked and to make the many necessary genetic changes.

The pressure to help feed the growing population at a time when climate change is making more land marginal for agriculture is "the burden that plant biologists bear," Voytas says. But he's optimistic. Over much of the last 50 years, he points out, crop productivity has made repeated gains, attributable first to the use of hybrid seeds, then to the new plant varieties introduced during the so-called Green Revolution, and "even to the first GM plants." The introduction of the new genome engineering tools, he says, "will be another inflection point."

If he's right, it might be just in time.

HEAT WAVE

For agronomists, plant breeders, and farmers, it's all about yield—the amount a crop produces in a hectare. The remarkable increases in crop yields beginning in the middle of the 20th century are the main reason that we have enough food to go from feeding three billion people in 1960 to feeding seven billion in 2011 with only a slight increase in the amount of land under cultivation. Perhaps most famously, the Green Revolution spearheaded by the Iowa-born plant pathologist and geneticist Norman Borlaug substantially increased yields of wheat, corn, and rice in many parts of the world. It did so, in part, by introducing more productive crop varieties, starting in Mexico and then in Pakistan, India, and other countries. But for at least the past decade, increases in the yields of wheat and rice seem to have slowed. Yields of wheat, for example, are growing at roughly 1 percent annually; they need to increase nearly 2 percent annually to keep up with food demand over the long term. Agricultural experts warn that yields will have to improve for other crops as well if we are to feed a rapidly growing population—and yet rising temperatures and other effects of global climate change will make this tougher to achieve.

Agricultural yields will have to improve if we are to feed a rapidly growing population.

David Lobell, a professor of environmental earth system science at Stanford University, has a calm demeanor that belies his bleak message about how global warming is already affecting crops. The effects of climate change on agriculture have been widely debated, but recently Lobell and his collaborators have clarified the projections by combing through historical records of weather and agricultural production. They found that from 1980 to 2008, climate change depressed yields of wheat and corn; yields still rose during that time, but overall production was 2 to 3 percent less than it would have been if not for global warming. This has held true across most of the regions where corn and wheat are grown.

The finding is startling because it suggests that global warming has already had a significant impact on food production and will make an even bigger difference as climate change intensifies. "Anything that causes yield [growth] to flatten out is a concern," says Lobell. And while overall yields of wheat and corn are still increasing, he says, "climate change becomes a concern long before you have negative yield trends."

Even more disturbing, Lobell and his collaborator Wolfram Schlenker, an economist at Columbia University, have found evidence that in the case of several important crops, the negative effect of global warming is more strongly tied to the number of extremely hot days than to the rise in average temperatures over a season. If that's true, earlier research might have severely underestimated the impact of climate change by looking only at average temperatures.

Schlenker's calculations show steady increases in corn and soybean yields as the temperature rises from 10 °C into the 20s—but at around 29 °C for corn and 30 °C for soybeans, the crops are "hit hard" and yields drop dramatically. In subsequent work, Lobell showed that hot days were doing far more damage to wheat in northern India than previously thought.

A surprising and troubling detail of the research, says Schlenker, is that crops and farmers don't seem to have adapted to the increased frequency of hot days. "What surprised me most and should inform us going forward," he says, "is that there has been tremendous progress in agricultural breeding—average yields have gone up more than threefold since the 1950s—but if you look at sensitivity to extreme heat, it seems to be just as bad as it was in the 1950s. We need to have crops that are better at dealing with hot climates." During the heat wave that hit much of the United States in 2012, he says, yields of corn were down 20 percent, and "2012 is not that unusual a year compared to what the climate models predict will be a new normal pretty soon."

It's possible that plants are simply hardwired to shut down at temperatures above 30 °C. Indeed, Schlenker says he's not convinced that crops can be engineered to adapt to the increased frequency of hot days, though he hopes he's wrong. Likewise, Lobell wants his work to better define which aspects of climate change are damaging crops and thus help target the needed genetic changes. But, like Schlenker, he is unsure whether genetics can provide much of an answer.

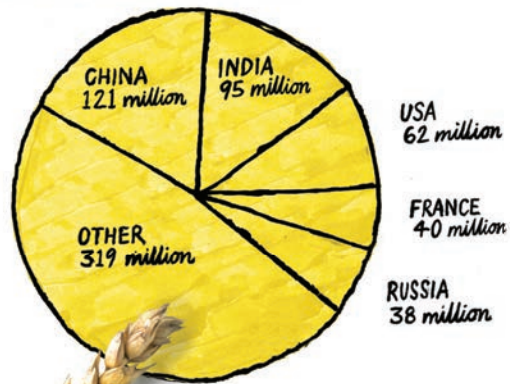
In California's Central Valley, one of the world's most productive agricultural areas, UC Davis's Blumwald acknowledges that scientists have "never bred for stresses" like drought and heat. But he aims to change that. Inserting a combination of genes for tolerance to heat, drought, and high soil salinity into rice and other plants, Blumwald is creating crops that have at least some

WHEAT

THE MOST WIDELY GROWN CROP IN THE WORLD, WHEAT PROVIDES 21 PERCENT OF OUR CALORIES.

TOP GROWING COUNTRIES (2012)

Global total: 675 million metric tons



TRANSGENIC WHEAT

461 The number of U.S. permits and notifications for testing since 1985

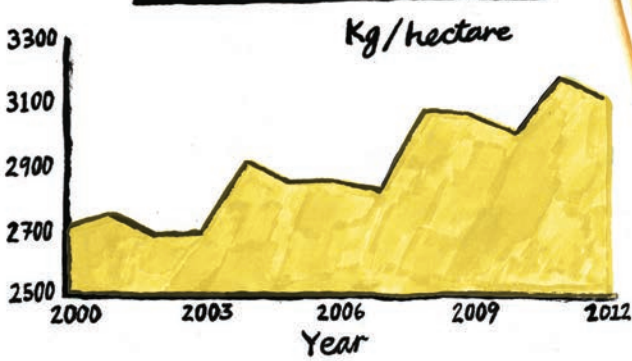
0 Number of commercial varieties

POTENTIAL TRAITS: Herbicide tolerance, drought tolerance, disease resistance

The demand for wheat is expected to increase **60%** by **2050**

Wheat is grown on **215** million hectares, producing **630** million metric tons annually.

GLOBAL WHEAT YIELD



CLIMATE CHANGE BOTTOM LINE

Wheat is extremely heat sensitive. Research shows production of wheat was significantly less from 1980 to 2008 than it would have been without global warming.

DATA FROM USDA, UN, INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER

advantages during extreme weather conditions, particularly during key times in their growth cycle.

The challenge is to avoid reducing yields under good growing conditions. So Blumwald has identified a protein that activates the inserted genes only under adverse conditions. "There's no cure for drought. If there's no water, the plant dies. I'm not a magician," he says. "We just want to delay the stress response as long as possible in order to maintain yields until the water comes."

DAILY BREAD

A field just north of London on the grounds of Rothamsted Research, which bills itself as the world's longest-running agricultural research station (founded in 1843), is one of the focal points of Europe's continuing battle over genetically modified foods. The controversy here is over an 80-by-80-meter field of wheat, some of it genetically modified to produce a hormone that repels aphids, a common insect pest. In 2012, a protester climbed a low fence and scattered conventional wheat seeds among the GM plants in an attempt to sabotage the trial. The scientists at Rothamsted had the seeds vacuumed up, hired several extra security guards, and built a second fence, this one three meters high and topped with a curved overhang to keep it from being scaled. Later, a few hundred protesters marched arm in arm to the edge of the fenced-in field before they were stopped by the police.

Wheat is vulnerable to one of the world's most devastating plant diseases: stem rust.

The fuss at Rothamsted is just one hint that the next great GMO controversy could involve transgenic wheat. After all, wheat is the world's most widely planted crop, accounting for 21 percent of the calories consumed globally. Meddling with a grain that makes the daily bread for countless millions around the world would be particularly offensive to many opponents of genetically modified foods. What's more, wheat is a commodity grain sold in world markets, so approval of GM wheat in a leading exporting country would likely have repercussions for food markets everywhere.

Wheat is also emblematic of the struggles facing agriculture as it attempts to keep up with a growing population and a changing climate. Not only have the gains in yield begun to slow, but wheat is particularly sensitive to rising temperatures and is grown in many regions, such as Australia, that are prone to severe droughts. What's more, wheat is vulnerable to one of the world's most dreaded plant diseases: stem rust, which is threatening the fertile swath of Pakistan and northern India known as the Indo-Gangetic Plain. Conventional breeding techniques have made remarkable progress against these problems, producing varieties that are increasingly drought tolerant and disease resistant. But biotechnology offers advantages that shouldn't be ignored.

"Climate change doesn't change [the challenge for plant breeders], but it makes it much more urgent," says Walter Falcon, deputy director of the Center on Food Security and the Environment at Stanford. Falcon was one of the foot soldiers of the Green Revolution, working in the wheat-growing regions of Pakistan and in Mexico's Yaqui Valley. But he says the remarkable increases in productivity achieved between 1970 and 1995 have largely "played out," and he worries about whether the technology-intensive farming in those regions can be sustained. He says the Yaqui Valley remains highly productive—recent yields of seven tons of wheat per hectare "blow your mind"—but the heavy use of fertilizers and water is "pushing the limits" of current practices. Likewise, Falcon says he is worried about how climate change will affect agriculture in the Indo-Gangetic Plain, the home of nearly a billion people.

Asked whether transgenic technology will solve any of these problems, he answers, "I'm not holding my breath," citing both scientific reasons and opposition to GM crops. But he does expect advances in genetic technologies over the next decade to create wheat varieties that are better equipped to withstand pests, higher temperatures, and drought.

It is quite possible that the first and most dramatic of the advances will come in adapting crops to the shifting patterns of disease. And as Teagasc's Ewen Mullins puts it, "if you want to study plant diseases, you come to Ireland."

A hundred kilometers from the idyllic fields in Carlow, Fiona Doohan, a plant pathologist at University College Dublin, is developing wheat varieties that stand up to local diseases and trying to understand how plant pathogens might evolve with climate change. At the school's agricultural experiment station, she uses growing chambers in which the concentration of carbon dioxide can be adjusted to mimic the higher levels expected in 2050. The experiments have yielded a nasty surprise. When wheat and the pathogens that commonly afflict it are put in the chamber with the increased levels of carbon dioxide, the plant remains resistant to the fungus. But when both are separately grown through several generations under 2050 conditions and then placed together, Doohan says, the plants "crash." This suggests, ominously, that plant pathogens might be far better and faster than wheat at adapting to increased carbon dioxide.

Next to the building is an apple orchard with representatives of trees grown all over Ireland, including heirloom varieties that have been planted for centuries. Doohan looks at them fondly as she walks past, the ground covered by fallen apples. At the far end of the orchard is a row of greenhouses, including a small one in which genetically modified plants are tested. Inside is a particularly promising transgenic wheat that is proving resistant to the types of rust disease common in Ireland. The new gene is also increasing the plant's grain production, says Doohan, who created the variety with her colleagues. She's clearly delighted by the results. But, she quickly adds, there are no plans to test the GM wheat out in the field in Ireland, or anywhere else in Europe. At least for now, the promising variety of wheat is doomed to stay in the greenhouse.

David Rotman is the editor of MIT Technology Review.

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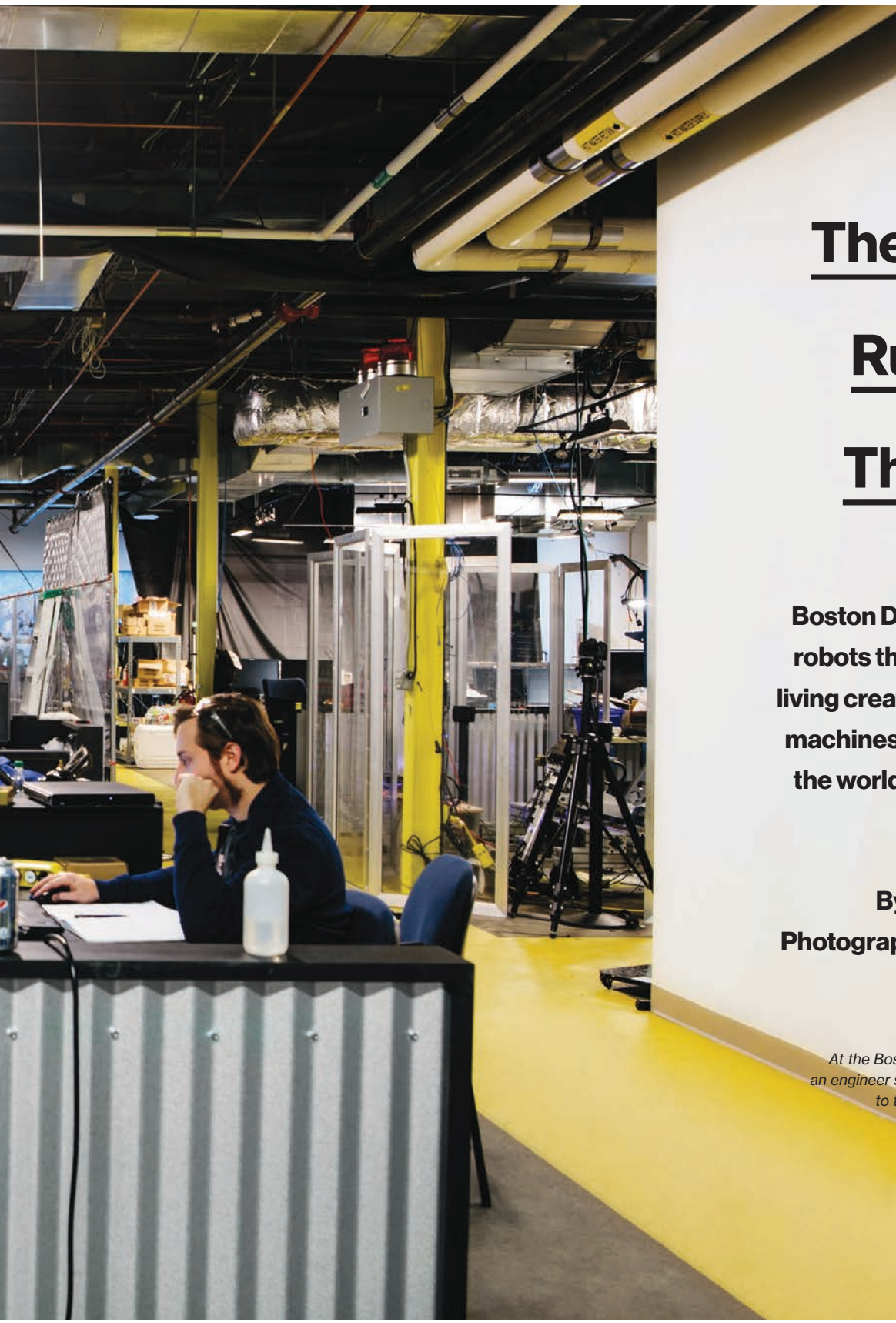
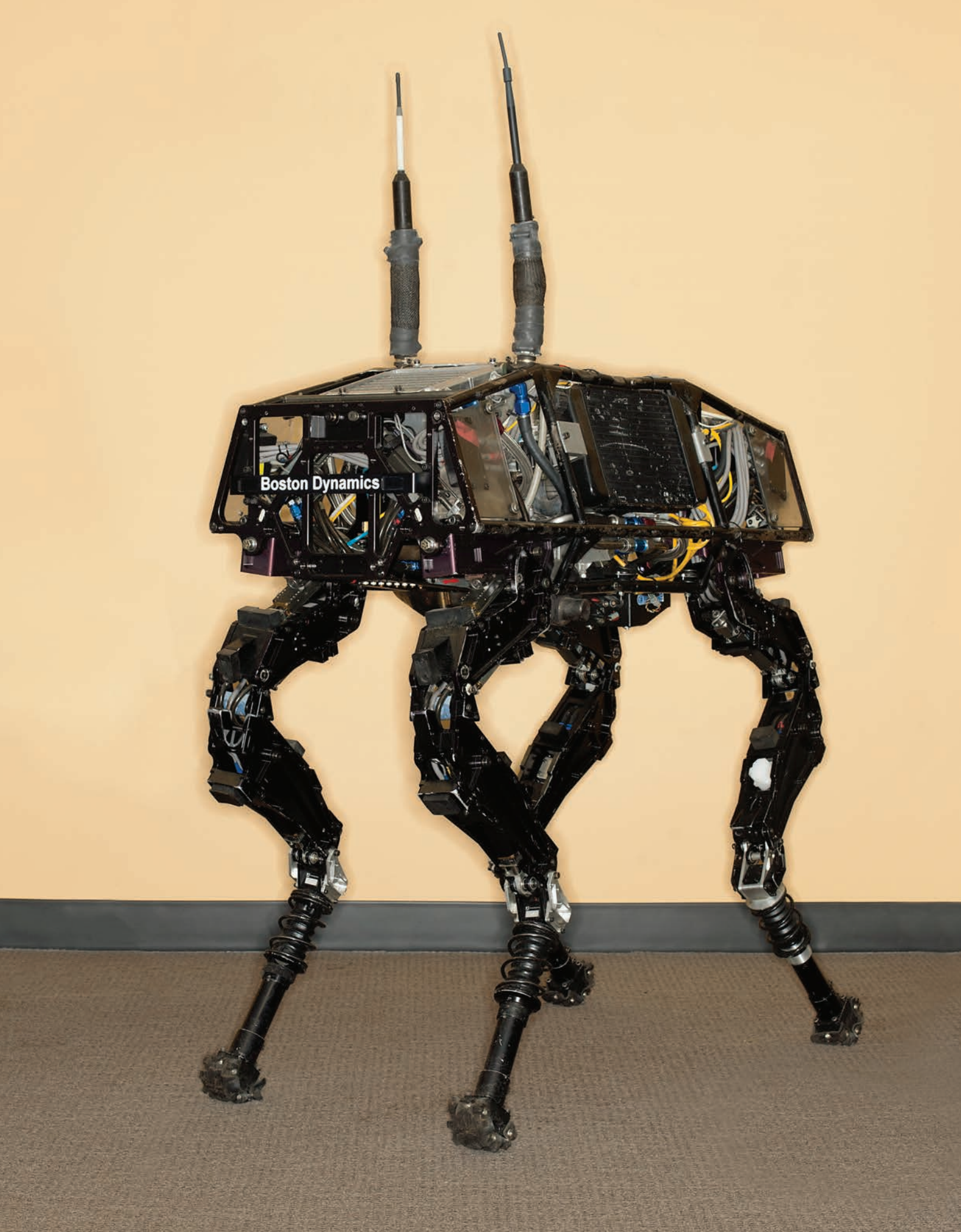


The Robots Running This Way

Boston Dynamics is building robots that walk and run like living creatures. Some of these machines are now headed for the world's toughest terrain.

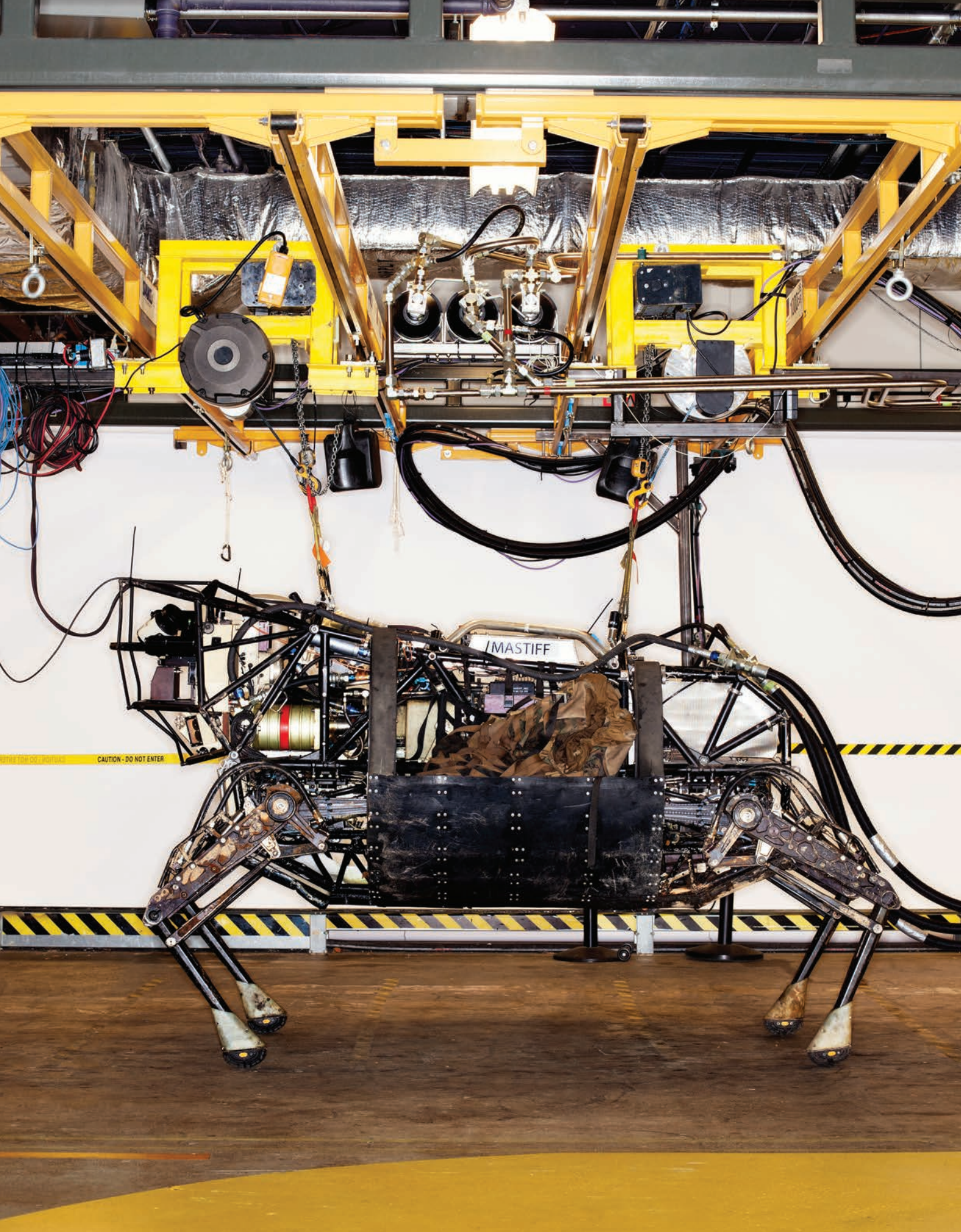
By Will Knight
Photographs By Adam DeTour

At the Boston Dynamics research lab, an engineer sits behind a protective screen to test control software.


Boston Dynamics

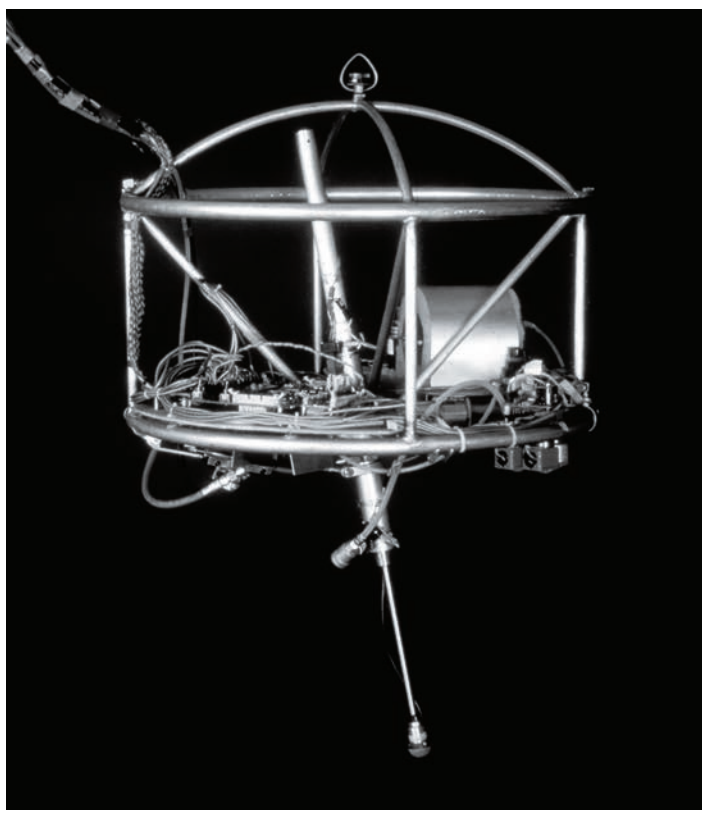
Boston Dynamics robots use hydraulic power and multiple sensors to steady themselves on difficult ground. The robot shown here, called BigDog, is the size of a St. Bernard and weighs 110 kilograms. It has been tested walking on many different kinds of terrain.

RIGHT: COURTESY OF BOSTON DYNAMICS

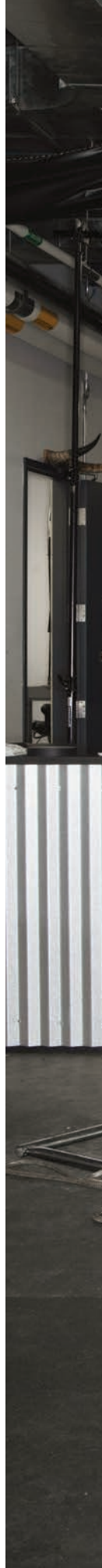

MASTIFF
CAUTION - DO NOT ENTER

The Legged Squad Support System can carry 180 kilograms and uses computer vision to follow a human. Built with funding from the U.S. military, the robot is now being tested by the Marines. Above, it covers terrain inaccessible by wheeled vehicle in Twentynine Palms, California.

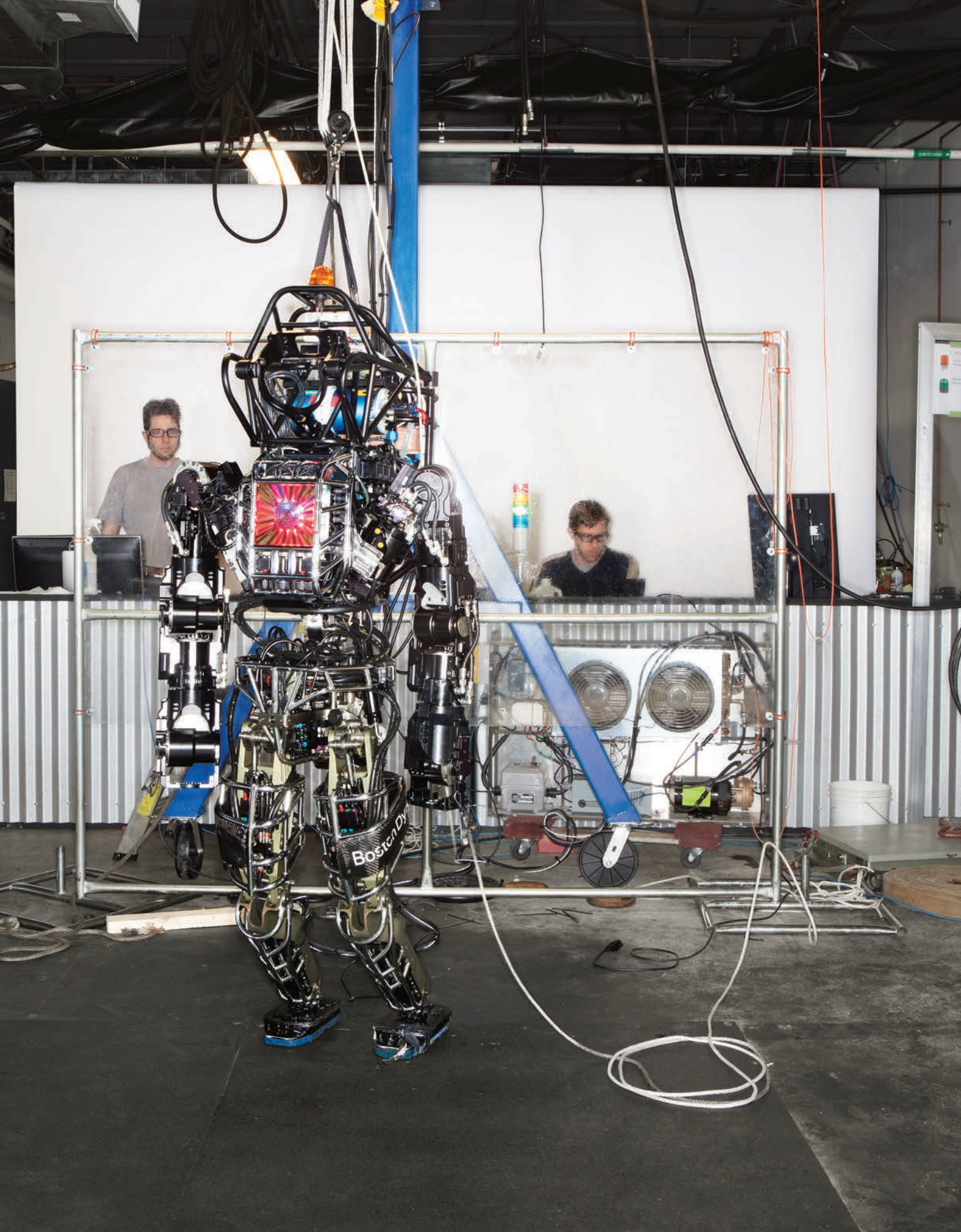
RIGHT: COURTESY OF BOSTON DYNAMICS



In 1983, Marc Raibert, now CTO of Boston Dynamics, developed the one-legged hopping robot shown above. The dynamic balancing principles employed by this robot are used in Boston Dynamics machines including Atlas, the bipedal humanoid shown on the opposite page. Developed with funding from DARPA, Atlas is designed to navigate human environments and perform dangerous rescue missions.



LEFT: © LEG LABORATORY



Portrait by David Hughes

The CEO of Box is building an online file storage system designed to reshape industries.

By Ted Greenwald

AARON LEVIE BOUNDS ONSTAGE WITH the swagger of a standup comic. But he's not performing at the Comedy Store. He's in the Grand Ballroom at San Francisco's Hilton Union Square kicking off BoxWorks, his company's annual customer conference. Steve Jobs had his black turtleneck, Mark Zuckerberg has his gray hoodie; Levie's uniform is a staid black suit, a capitulation to the buttoned-down enterprise software market he aims to conquer. But he spices it up with a cheeky pair of colorful sneakers. Today they're bright red.

First order of business: the choice of one of his favorite bands, Blink 182, to close Box's two-day event. "We wanted to engage a younger demographic, so the first choice was Miley Cyrus," he says, calmly pacing the stage. "But in her contract, she stipulated that we needed to call the conference BoxTwerks." A chuckle ripples through the crowd. "Don't worry," he adds. "The jokes will get better."

They do. He roasts competitors like Microsoft (if he were considered to fill Redmond's newly empty CEO slot, would he have to fix the company or just get a new version of Windows out the door?) and industry icons like Larry Ellison (if New Zealand beats the Oracle CEO's boat in the America's Cup race, Ellison could simply acquire the country and shut it down). He even pokes a little fun at himself, showing a goofy picture of what he calls Box's entry in the next America's Cup: Levie pedaling a paddleboat across San Francisco Bay.

It's a lighthearted performance, but Levie, 28, takes his business seriously. He wants to provide the Internet with something fundamental: a storage system for business-related files that employees can access on any device. In his view, Box's technology is the infrastructure for a new way of working that's more spontaneous, fluid, collaborative, and productive.

That aspiration places Box between the enterprise software equivalents of Scylla and Charybdis. On one side is Microsoft, still a formidable force in the business software market. On the other is Dropbox, a phenomenally popular consumer-focused service that sneaks past corporate gatekeepers tucked inside employees' smartphones. And yet Box may do far more than either rival to virtualize the office.

The forces propelling Box have been gathering for decades. When mainframe computers gave way to PCs, large companies stocked up on packaged software from companies like Microsoft and Oracle. To run it, they invested in racks of servers, fleets of desktop PCs, and armies of information technology managers. Then along came the Internet. Programs like Salesforce offered software as a service, eliminating packaged software, automating updates, and saving infrastructure and management overhead by running in the cloud. With the rise of mobile devices, employees brought their personal devices into the office, packed with their own apps that routed around management-sanctioned software—a phenomenon encapsulated by the phrase "the consumerization of IT." The traditional corporate IT department began to appear obsolete.

Along the way, IT managers lost control over one of a company's most valuable assets: documents. If employees use their own e-mail accounts to share secret contracts or store presentations about upcoming products in a consumer-grade file storage service, there's a risk that the details could ricochet around the blogosphere in minutes.

Levie has designed Box to put the IT department back in control, to the delight of customers including Amazon, GlaxoSmithKline, Procter & Gamble, Siemens, and Toyota—97 percent of the Fortune 500, as he's fond of saying. Like a number of similar services, Box provides file storage in the cloud—remote data centers somewhere on the Internet. It's simple enough for individuals to get up and running on their own at little or no cost. Users access the service from Box's website, its mobile app, or software running on a PC. Move a file into Box, and the file becomes available on many devices; change the file, and the alterations propagate to the other devices as well. But beneath the surface, Box provides features like security and permissions control that let corporate IT departments manage the way information flows through organizations. To get these professional-grade features, companies pay Box between $5 and $35 monthly for every employee who uses the system.

Data stored in the cloud in 2012:

100 million terabytes

Box has 20 million users. That's few compared with Microsoft, which holds

BATTLE FOR OFFICE SUPREMACY

Box and its main rivals all store files online. Their role in businesses of the future will be defined by the additional benefits they offer.

Box

Launched:
2005

Advantages:
Geared for businesses from the beginning, Box has a head start on many enterprise- and industry-specific features. Box is focusing on international reach, app integration, and new ways to manipulate the files it stores.

Dropbox

Launched:
2008

Advantages:
Dropbox is very easy to use and adept at synchronizing data across multiple devices. Its immense popularity among individual users has propelled it into four million businesses, and the company is working hard to increase that.

SharePoint

Launched:
2001

Advantages:
Microsoft's relationships with IT departments have helped it sell 135 million SharePoint licenses. Unlike SkyDrive, Microsoft's consumer-grade storage service, SharePoint includes extensive messaging and collaboration tools.

CLOUD-DATA SOURCE: IDC

more than 385 million accounts between its consumer- and business-focused file storage services, SkyDrive and SharePoint. It's also puny next to Dropbox, with 200 million accounts. Even so, Box has advantages over both in the corporate market. Largely written a decade ago, Microsoft's code is intricately entwined with a premobile, desktop-based, intranet-bound way of organizing corporate IT. The company has been struggling to catch up with the rise of the cloud and mobile computing, while Box is designed to fit smoothly into an increasingly informal work culture born of easy-to-use Web and mobile apps. As for Dropbox, it has spent years catering to consumers and might well spend many more building enterprise-grade technology.

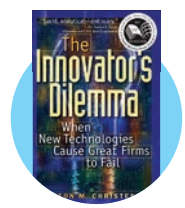
But Levie's vision may be the decisive factor. Box doesn't merely store documents, he points out, but facilitates communication around them. And communication—not a nicely formatted, ready-to-publish document—is the crucial product of work. The latest updates to Box's service make document archives interactive, allowing users to add metadata, scroll rapidly through high-resolution previews, and search for snippets of text. The system is also taking a leap from content storage to content generation with the addition of Box Notes, a basic text editor that encourages collaboration: avatar icons skip across the screen in real time to show who's typing what.

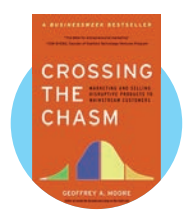
In this way, Levie threatens more than just other cloud storage providers. He's shoveling coal into a locomotive of cloud-based enterprise services that promises to mow down any software company if it can't translate its desktop offerings into sleek mobile apps that interact with their users' data anytime, anywhere, on any device.

"The cloud is going to drive a new way of working," he says after the conference. "The ability to deliver medical research from a lab to a doctor in seconds, or from an educational publisher to a student—it's about real-time, collaborative, synchronous information sharing. It's going to change work. Not just the technology of work, but work itself."

THE CLOUD—OR, MORE PRECISELY, the rigor of running a rapidly expanding cloud-based software company—has certainly shaped Levie's routine. At 11 A.M., he arrives at Box's office, a sprawling workspace with an Italianate exterior in Los Altos, California. He attends meetings until 6:30 P.M. or so, whereupon he'll have another meeting over dinner or walk down El Camino Real to a Vietnamese pho house. After returning to the office, he naps for 20 minutes. Then he's back on the job. He leaves at 2 A.M. and heads for the nearby apartment he shares with his longtime girlfriend, and he's asleep by 3:30. By 10:15 A.M. he's awake and ready to resume plotting his conquest of the workplace.

During the brief time between arriving at his apartment and hitting the pillow, he reads: manuals of business strategy, biographies of celebrated entrepreneurs, histories of iconic companies. "He has read more books about the tech industry than anyone I know," says Josh Stein, an early champion of his at the VC firm Draper Fisher Jurvetson, one of the companies that have collectively invested more than $400 million in Box. Indeed, in conversation, much of the time Levie sounds less like a first-time entrepreneur than a professor lecturing on the latest theories of the technology adoption cycle.





"He has read more books about the tech industry than anyone I know," says venture capitalist Josh Stein. Above, some of Levie's favorite bedtime stories.

These bedtime stories are also scary enough to keep Levie awake (and in the office) at night. "It creates this deep paranoia," he says. "At any moment, you're making decisions that might determine the survival of your company. That doesn't lend itself to being in Hawaii for a month."

Aaron Levie has never taken much interest in leisure. Born in Boulder, Colorado, he was pulling weeds and walking neighbors' dogs for money by the time he was eight years old. When he was 10, his family moved to Mercer Island, a strip of land in Lake Washington between Seattle and Bellevue, a 20-minute drive from Microsoft's headquarters. The tech bubble was beginning to inflate; he and his parents, a chemical engineer and a speech pathologist, discussed business ideas around the dinner table. He was an indifferent student, but he spent his free time building websites: a search engine, a real-estate site, a downloadable toolbar that pushed news. ("It probably gave you a virus," he jokes.) His friend Jeff Queisser, now Box's vice president of technical operations, supplied technical know-how. "About every month, I'd get a call at 1 A.M. to come to his hot tub, where he'd pitch an idea," Queisser recalls.

Levie wanted to be a movie director in the mold of Quentin Tarantino, but the University of Southern California's film school rejected his application. He settled for USC's Marshall School of Business. During his sophomore year in 2004, a marketing class project led him to research online data storage. Early providers of that technology had been devastated when the dot-com bubble burst in 2001. Yet technology had evolved to the point where storing files on a hard drive in the cloud could be practical for mainstream computer users. "There was a disconnect between companies that existed and the size of the opportunity," he says.

He roped in Dylan Smith, a Mercer Island friend who was studying economics at Duke University, to handle finance, and in April 2005 the pair launched Box on roughly $20,000 Smith had won at online poker. Within weeks, they had thousands of customers. Off to a heady start, they sent an e-mail to the billionaire Mark Cuban, whose popular blog, they thought, could boost their public profile.

Cuban responded with a request to invest. The founders gladly cashed his $350,000 check, dropped out of college, and moved into Levie's uncle's garage in Berkeley.

By 2007, Box's user base had doubled 20 times over and annual revenue was around $1 million. But Levie felt uneasy. The price of hard disks was falling 50 percent every 12 to 18 months. As online storage became a commodity, what would stop Apple, Google, or Microsoft from giving it to customers free? He noticed that the customers who stuck around longest weren't storing MP3s or JPEGs but Word, Excel, and PDF files. In other words, business customers. Moreover, their colleagues would follow their lead, generating a steady stream of new sign-ups. Levie decided to ditch the fickle consumer market and focus on serving enterprises, companies with thousands of employees, which would be willing to pay for a storage service tailored to their needs. He set about adding the capabilities required by large businesses: search, security, and the ability to create and delete accounts, manage file access, and grant permission to view, edit, or delete.

In embracing enterprise customers, Levie took on what was, at the time, the biggest tech company in the world: Microsoft. And Redmond might have crushed him but for a stroke of luck. In late 2007, Apple introduced the iPhone. For many people, the device was their first smartphone, and the apps they downloaded transformed e-mail, document viewing, and even document editing into mobile experiences. Suddenly, employees were liberated from the strictly managed environment of corporate IT, with its password-protected intranets and sluggish virtual private networks. If they found the office regime too restrictive, they simply downloaded apps that ran in the cloud—including one from Box.

As it happened, Apple, Google, and Microsoft did introduce consumer-grade file storage services in the cloud. Microsoft launched SkyDrive in 2007, to a collective yawn outside the desktop-bound world of Windows. Apple's iCloud limped out in 2011, and Google Drive finally appeared in 2012, fully seven years after Box's debut. Meanwhile, Dropbox launched in 2008 and quickly garnered rave reviews, a rapidly growing user base, and investments from top VCs. Today, it dominates the consumer market that Box abandoned.

But Levie never looked back.

Amount spent on public cloud services in 2012:

$37 billion

SOURCE: IDC

BOX'S OFFICE IS A WARREN OF DESKS, partitions, and meeting rooms with names like Watson (for IBM's founder) and Revenue Bong (Levie's off-the-cuff misremembering of the marketing phrase "sales funnel"). In the room called Fry's (as in the electronics retailer), the CEO sits with eight colleagues around a long oak table. He's wearing his black suit jacket over a bright turquoise T-shirt bearing the Box logo and a rainbow. It's an odd combination, but it barely hints at the rest of his ensemble, hidden beneath the tabletop: neon-yellow shorts, calf-high turquoise socks (to match the shirt), and crimson sneakers. Today is National Coming Out Day, and the outfit is a show of solidarity.

With two cups of coffee on the table before him, Levie peers intently at the slides projected on the far wall. He drills the team, asking whether a given set of numbers are actual or projected and why the targets are so low. ("Five million for 2013? We should do 10. Let's do 20!") He swivels and tips his chair as he talks. Within a few minutes, the second cup is empty.

The team is mapping out a strategy for View API, the technology Box acquired last year with a company called Crocodoc. View API is a document-viewing engine that translates Word, Excel, PowerPoint, and PDF files into HTML5 format. In practical terms, this makes it easy for developers to display files stored in Box on Web pages. But there's more to it. First, it rapidly renders documents so they look almost exactly as they would in their native application. Second, the technology deconstructs them into their component parts, which could eventually be manipulated in software. In a diagram of a municipal water system, for instance, the pumps might light up when a user rolls the cursor over them, revealing data about how much water flows through them.

If all goes according to plan, View API will act as a gateway drug for the Box platform as a whole. Any company that's overwhelmed by e-mail attachments or wishes to embed documents in Web pages—from manufacturers to universities to publishers to online stores—will find it convenient to store them in Box. In addition, apps offered by some 700 Box partners will let employees store the files they generate directly in Box. Workers will find that they can attach metadata—associating, say, a driver's license number with an insurance claim—or program the system to forward any incoming document that includes a phone number to the sales team.

As the meeting winds to a close, Levie stands up, revealing his full Coming Out Day costume. "I'm going to jump out," he says, and strides from the room on bare, caffeine-fueled legs. Moments later, a Box employee pokes his head in the door. "Aaron just ran by in a pair of yellow shorts," he says. "Is everything okay?"

LEVIE OPENS THE GLASS DOOR OF THE pho house at 6:30 P.M. sharp and takes a booth. The waitress doesn't even ask for his order; it's always chicken soup, extra noodles, and a can of A&W root beer. Stirring his bowl, he explains that Box's prospects depend on its ability to transform work from a serial march of e-mails, meetings, and reports to a parallel process called "continuous productivity."

The phrase comes from, of all people, a former Microsoft executive—Steven Sinofsky, who at various times oversaw Windows, Office, and Internet Explorer, and left the company abruptly in late 2012 after the turbulent release of Windows 8. Levie saw the news and contacted him by poking him on Facebook. "Who does that anymore?" Sinofsky says. "I guess he thought I was an old person." The two met over chicken pho with extra noodles, and Sinofsky soon joined Box as an advisor.

Sinofsky's notion of continuous productivity goes like this: In traditional organizations, information is concentrated at the top of the management hierarchy and dispensed on a schedule. In connected, mobile organizations, on the other hand, every employee has equal access to information, potentially in real time as it accrues. This tends to flatten the management hierarchy; the boss may call the shots, but they're readily redirected by employees. Moreover, workers can share information easily with people outside the company. This tends to dissolve organizational boundaries. The tempo of activity picks up, data replaces assumptions, and execution takes precedence over strategy.

Sinofsky's ideas reminded Levie of a 1937 essay entitled "The Nature of the Firm," in which economist Ronald Coase laid out a rationale for why companies exist: they save the cost, in time and money, of organizing, disbanding, and reorganizing for every new project. "That was true in an era when we didn't have common interfaces between organizations," Levie explains. Not anymore. Increasingly, companies can assemble the resources they need on the fly: data centers for hire, contract manufacturing, crowdsourcing. More to the point, as the pace of change accelerates, they have no other choice.

Levie wants to put Box at the heart of this transformation. A key part of his plan is to add features and apps tailored to the needs of specific industries, including education, finance, government, health care, law, media, packaged goods, and retailing. Next, Levie envisions connecting not just companies but the industries themselves. To make a Hollywood movie, he points out, files must be shared among studios, agents, distributors, promoters, and lawyers. "At every point of sharing, there's a slowdown," he says. "The big question is how to accelerate that process." His answer: by linking partners, suppliers, contractors, and so on to a synchronized collaboration service in the cloud.

Levie contacted Steven Sinofsky by poking him on Facebook. "Who does that anymore?" Sinofsky says. "I guess he thought I was an old person."

A bigger question is whether businesses should surrender their information to a cloud service provider. Many find the cost savings compelling. But some competitors are betting that enterprises will need to keep files in-house, either because those files are extremely large—making them slow to upload, synchronize, and access online—or because they're simply too sensitive to store on the public Internet. A company called Egnyte, for instance, offers a so-called hybrid solution that combines cloud and on-premises storage. Such an arrangement might appeal to anyone worried by revelations that the U.S. government—or other snoops—can plunder data held in the cloud.

Scripps Networks, which produces shows for cable TV, is an early explorer of this terra incognita. The company, which is based in Knoxville, Tennessee, and maintains offices in London, Rio de Janeiro, and Singapore, adopted Box after the CEO gave every senior executive an iPad in 2011 without informing the IT department. Scripps had been using SharePoint, but Microsoft's program didn't support Apple devices at the time, and it proved unwieldy for ad hoc collaboration, says Chuck Hurst, VP of media and content distribution. Instead, employees were sharing confidential files through Dropbox and other systems that lacked enterprise administration capabilities. The legal department was having fits.

Hurst brought in Box in late 2012, and it has become integral to Scripps's operations. The marketing department uses it to exchange assets with advertising agencies. The sales reps run presentations directly out of Box. "They can share things quickly and we don't get in their way," he says, "so they're happy." Box isn't yet ready to take on the massive files required for production and broadcast video, but Hurst believes it will eventually. At that point, it could revolutionize the way things are done in his industry.

At the restaurant, Levie slurps up the last of his pho. Seven o'clock is only the middle of his workday. The office will be mostly empty when he returns, but that leaves him free to contemplate his next moves. "We're only 1 percent of the way toward what's possible in this space," he says. Personal computers didn't transform business until there was one on every desk, he points out. Similarly, cloud computing won't transform the way we work until every office across the world is using it. Meanwhile, people born in 2014 will never use a desktop or laptop. They'll know only phones, tablets, Google Glass, and whatever comes next. "The PC shift affected millions; this will affect billions," he says. "The opportunity is way larger than in previous eras of enterprise computing."

With that, he pays the check and heads back to work, where the task of making an already always-on world spin ever faster, more efficiently, and more productively never ends.

Ted Greenwald is a freelance journalist who has written for Bloomberg Businessweek, Fortune, *and* Wired. *He profiled Ben Milne in the September/October 2013 issue.*

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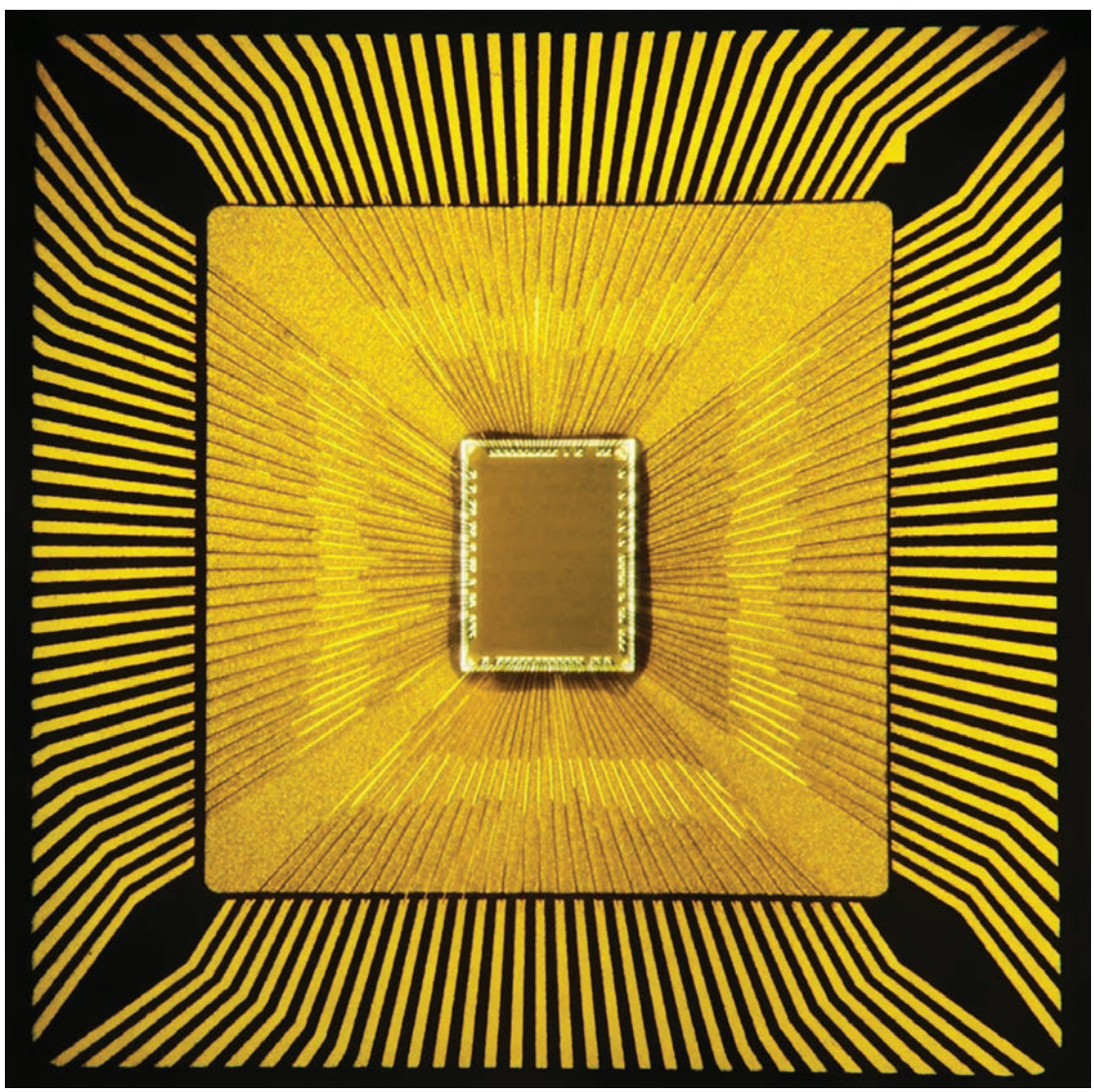

This computer chip, made by IBM in 2011, features components that serve as 256 neurons and 1,024 synapses.

MIT TECHNOLOGY REVIEW
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Thinking in Silicon

Microchips modeled on the brain may excel at tasks that baffle today's computers.

by Tom Simonite

Picture a person reading these words on a laptop in a coffee shop. The machine made of metal, plastic, and silicon consumes about 50 watts of power as it translates bits of information—a long string of *1*s and *0*s—into a pattern of dots on a screen. Meanwhile, inside that person's skull, a gooey clump of proteins, salt, and water uses a fraction of that power not only to recognize those patterns as letters, words, and sentences but to recognize the song playing on the radio.

Computers are incredibly inefficient at lots of tasks that are easy for even the simplest brains, such as recognizing images and navigating in unfamiliar spaces. Machines found in research labs or vast data centers can perform such tasks, but they are huge and energy-hungry, and they need specialized programming. Google recently made headlines with software that can reliably recognize cats and human faces in video clips, but this achievement required no fewer than 16,000 powerful processors.

A new breed of computer chips that operate more like the brain may be about to narrow the gulf between artificial and natural computation—between circuits that crunch through logical operations at blistering speed and a mechanism honed by evolution to process and act on sensory input from the real world. Advances in neuroscience and chip technology have made it practical to build devices that, on a small scale at least, process data the way a mammalian brain does. These "neuromorphic" chips may be the missing piece of many promising but unfinished projects in artificial intelligence, such as cars that drive themselves reliably in all conditions, and smartphones that act as competent conversational assistants.

"Modern computers are inherited from calculators, good for crunching numbers," says Dharmendra Modha, a senior researcher at IBM Research in Almaden, California. "Brains evolved in the real world." Modha leads one of two groups that have built computer chips with a basic architecture copied from the mammalian brain under a $100 million project called Synapse, funded by the Pentagon's Defense Advanced Research Projects Agency.

The prototypes have already shown early sparks of intelligence, processing images very efficiently and gaining new skills in a way that resembles biological learning. IBM has created tools to let software engineers program these brain-inspired chips; the other prototype, at HRL Laboratories in Malibu, California, will soon be installed inside a tiny robotic aircraft, from which it will learn to recognize its surroundings.

The evolution of brain-inspired chips began in the early 1980s with Carver Mead, a professor at the California Institute of Technology and one of the fathers of modern computing. Mead had made his name by helping to develop a way of designing computer chips called very large scale integration, or VLSI, which enabled manufacturers to create much more complex microprocessors. This triggered explosive growth in computation power: computers looked set to become mainstream, even ubiquitous. But the industry seemed happy to build them around one blueprint, dating from 1945. The von Neumann architecture, named after the Hungarian-born mathematician John von Neumann, is designed to execute linear sequences of instructions. All today's computers, from smartphones to supercomputers, have just two main components: a central processing unit, or CPU, to manipulate data, and a block of random access memory, or RAM, to store the data and the instructions on how to manipulate it. The CPU begins by fetching its first instruction from memory, followed by the data needed to execute it; after the instruction is performed, the result is sent back to memory and the cycle repeats. Even multicore chips that handle data in parallel are limited to just a few simultaneous linear processes.

That approach developed naturally from theoretical math and logic, where problems are solved with linear chains of reasoning. Yet it was unsuitable for processing and learning from large amounts of data, especially sensory input such as images or sound. It also came with built-in limitations: to make computers more powerful, the industry had tasked itself with building increasingly complex chips capable of carrying out sequential operations faster and faster, but this put engineers on course for major efficiency and cooling problems, because speedier chips produce more waste heat. Mead, now 79 and a professor emeritus, sensed even then that there could be a better way. "The more I thought about it, the more it felt awkward," he says, sitting in the office he retains at Caltech. He began dreaming of chips that processed many instructions—perhaps millions—in parallel. Such a chip could accomplish new tasks, efficiently handling large quantities of unstructured information such as video or sound. It could be more compact and use power more efficiently, even if it were more specialized for particular kinds of tasks. Evidence that this was possible could be found flying, scampering, and walking all around. "The only examples we had of a massively parallel thing were in the brains of animals," says Mead.

Brains compute in parallel as the electrically active cells inside them, called neurons, operate simultaneously and unceasingly. Bound into intricate networks by threadlike appendages, neurons influence one another's electrical pulses via connections called synapses. When information flows through a brain, it processes data as a fusillade of spikes that spread through its neurons and synapses. You recognize the words in this paragraph, for example, thanks to a particular pattern of electrical activity in your brain triggered by input from your eyes. Crucially, neural hardware is also flexible: new input can cause synapses to adjust so as to give some neurons more or less influence over others, a process that underpins learning. In computing terms, it's a massively parallel system that can reprogram itself.

Ironically, though he inspired the conventional designs that endure today, von Neumann had also sensed the potential of brain-inspired computing. In the unfinished book *The Computer and the Brain*, published a year after his death in 1957, he marveled at the size, efficiency, and power of brains compared with computers. "Deeper mathematical study of the nervous system ... may alter the way we look on mathematics and logic," he argued. When Mead came to the same realization more than two decades later, he found that no one had tried making a computer inspired by the brain. "Nobody at that time was thinking, 'How do I build one?'" says Mead. "We had no clue how it worked."

COURTESY OF IBM RESEARCH (PREVIOUS SPREAD); COURTESY OF WIKIMEDIA COMMONS (VON NEUMANN); COURTESY OF JAXA (SUN)

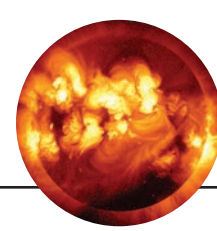
Brain Computing History

1958

In *The Computer and the Brain*, John von Neumann writes: "A deeper mathematical understanding of the nervous system ... may alter the way we look on mathematics and logic proper."

1987

Carver Mead publishes a paper about a silicon chip designed to mimic visual processing in the retina.



1996

Two silicon retina chips take flight on a balloon over Antarctica, helping the Flare Genesis observatory keep its camera pointed toward the sun.

Mead finally built his first neuromorphic chips, as he christened his brain-inspired devices, in the mid-1980s, after collaborating with neuroscientists to study how neurons process data. By operating ordinary transistors at unusually low voltages, he could arrange them into feedback networks that looked very different from collections of neurons but functioned in a similar way. He used that trick to emulate the data-processing circuits in the retina and cochlea, building chips that performed tricks like detecting the edges of objects and features in an audio signal. But the chips were difficult to work with, and the effort was limited by chip-making technology. With neuromorphic computing still just a curiosity, Mead moved on to other projects. "It was harder than I thought going in," he reflects. "A fly's brain doesn't look that complicated, but it does stuff that we to this day can't do. That's telling you something."

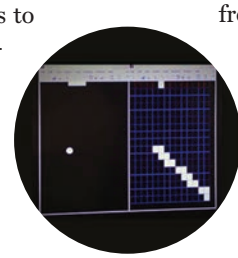
Neurons Inside

IBM's Almaden lab, near San Jose, sits close to but apart from Silicon Valley—perhaps the ideal location from which to rethink the computing industry's foundations. Getting there involves driving to a magnolia-lined street at the city's edge and climbing up two miles of curves. The lab sits amid 2,317 protected acres of rolling hills. Inside, researchers pace long, wide, quiet corridors and mull over problems. Here, Modha leads the larger of the two teams DARPA recruited to break the computing industry's von Neumann dependency. The basic approach is similar to Mead's: build silicon chips with elements that operate like neurons. But he has the benefit of advances in neuroscience and chip making. "Timing is everything; it wasn't quite right for Carver," says Modha, who has a habit of closing his eyes to think, breathe, and reflect before speaking.

IBM makes neuromorphic chips by using collections of 6,000 transistors to emulate the electrical spiking behavior of a neuron and then wiring those silicon neurons together. Modha's strategy for combining them to build a brainlike system is inspired by studies on the cortex of the brain, the wrinkly outer layer. Although different parts of the cortex have different functions, such as controlling language or movement, they are all made up of so-called microcolumns, repeating clumps of 100 to 250 neurons. Modha unveiled his version of a microcolumn in 2011. A speck of silicon little bigger than a pinhead, it contained 256 silicon neurons and a block of memory that defines the properties of up to 262,000 synaptic connections between them. Programming those synapses correctly can create a network that processes and reacts to information much as the neurons of a real brain do.

Setting that chip to work on a problem involves programming a simulation of the chip on a conventional computer and then transferring the configuration to the real chip. In one experiment, the chip could recognize handwritten digits from 0 to 9, even predicting which number someone was starting to trace with a digital stylus. In another, the chip's network was programmed to play a version of the video game Pong. In a third, it directed a small unmanned aerial vehicle to follow the double yellow line on the road approaching IBM's lab. None of these feats are beyond the reach of conventional software, but they were achieved using a fraction of the code, power, and hardware that would normally be required.

Modha is testing early versions of a more complex chip, made from a grid of neurosynaptic cores tiled into a kind of rudimentary cortex—over a million neurons altogether. Last summer, IBM also announced a neuromorphic programming architecture based on modular blocks of code called corelets. The intention is for programmers to combine and tweak corelets from a preëxisting menu, to save them from wrestling with silicon synapses and neurons. Over 150 corelets have already been designed, for tasks ranging from recognizing people in videos to distinguishing the music of Beethoven and Bach.



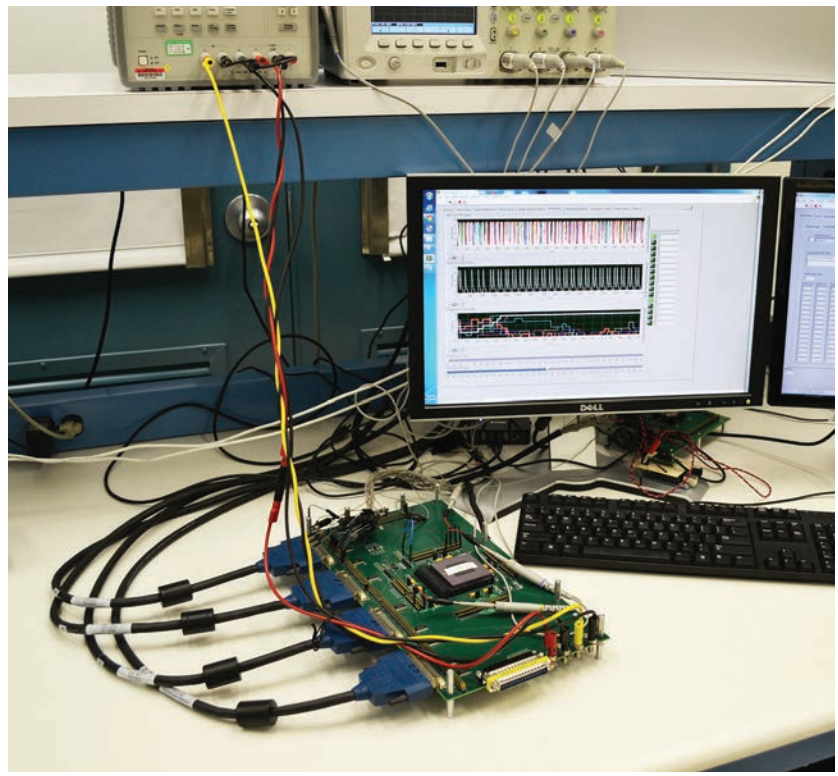
COURTESY OF IBM RESEARCH

2000 — A circuit of 16 silicon "neurons" that can selectively amplify input signals much like the cortex of the mammalian brain is described in *Nature*.

2008 — DARPA announces the Synapse program, "to break the programmable machine paradigm and define a new path forward for creating useful, intelligent machines."

2011 — IBM unveils its first Synapse chips. They can be programmed to play Pong and direct an unmanned aircraft to follow the road below.

2013 — HRL creates a chip that learns like the brain by altering the synapses that connect its own neurons.



A microchip developed at HRL learns like a biological brain by strengthening or weakening synapse-like connections.

Learning Machines

On another California hillside 300 miles to the south, the other part of DARPA's project aims to make chips that mimic brains even more closely. HRL, which looks out over Malibu from the foothills of the Santa Monica Mountains, was founded by Hughes Aircraft and now operates as a joint venture of General Motors and Boeing. With a koi pond, palm trees, and banana plants, the entrance resembles a hotel from Hollywood's golden era. It also boasts a plaque commemorating the first working laser, built in 1960 at what was then called Hughes Research Labs.

On a bench in a windowless lab, Narayan Srinivasa's chip sits at the center of a tangle of wires. The activity of its 576 artificial neurons appears on a computer screen as a parade of spikes, an EEG for a silicon brain. The HRL chip has neurons and synapses much like IBM's. But like the neurons in your own brain, those on HRL's chip adjust their synaptic connections when exposed to new data. In other words, the chip learns through experience.

The HRL chip mimics two learning phenomena in brains. One is that neurons become more or less sensitive to signals from another neuron depending on how frequently those signals arrive. The other is more complex: a process believed to support learning and memory, known as spike-timing-dependent plasticity. This causes neurons to become more responsive to other neurons that have tended to closely match their own signaling activity in the past. If groups of neurons are working together constructively, the connections between them strengthen, while less useful connections fall dormant.

Results from experiments with simulated versions of the chip are impressive. The chip played a virtual game of Pong, just as IBM's chip did. But unlike IBM's chip, HRL's wasn't programmed to play the game—only to move its paddle, sense the ball, and receive feedback that either rewarded a successful shot or punished a miss. A system of 120 neurons started out flailing, but within about five rounds it had become a skilled player. "You don't program it," Srinivasa says. "You just say 'Good job,' 'Bad job,' and it figures out what it should be doing." If extra balls, paddles, or opponents are added, the network quickly adapts to the changes.

This approach might eventually let engineers create a robot that stumbles through a kind of "childhood," figuring out how to move around and navigate. "You can't capture the richness of all the things that happen in the real-world environment, so you should make the system deal with it directly," says Srinivasa. Identical machines could then incorporate whatever the original one has learned. But leaving robots some ability to learn after that point could also be useful. That way they could adapt if damaged, or adjust their gait to different kinds of terrain.

The first real test of this vision for neuromorphic computing will come next summer, when the HRL chip is scheduled to escape its lab bench and take flight in a palm-sized aircraft with flapping wings, called a Snipe. As a human remotely pilots the craft through a series of rooms, the chip will take in data from the craft's camera and other sensors. At some point the chip will be given a signal that means "Pay attention here." The next time the Snipe visits that room, the chip should turn on a light to signal that it remembers. Performing this kind of recognition would normally require too much electrical and computing power for such a small craft.

Alien Intelligence

Despite the Synapse chips' modest but significant successes, it is still unclear whether scaling up these chips will produce machines with more sophisticated brainlike faculties. And some critics doubt it will ever be possible for engineers to copy biology closely enough to capture these abilities.

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Neuroscientist Henry Markram, who discovered spike-timing-dependent plasticity, has attacked Modha's work on networks of simulated neurons, saying their behavior is too simplistic. He believes that successfully emulating the brain's faculties requires copying synapses down to the molecular scale; the behavior of neurons is influenced by the interactions of dozens of ion channels and thousands of proteins, he notes, and there are numerous types of synapses, all of which behave in nonlinear, or chaotic, ways. In Markram's view, capturing the capabilities of a real brain would require scientists to incorporate all those features.

The DARPA teams counter that they don't have to capture the full complexity of brains to get useful things done, and that successive generations of their chips can be expected to come closer to representing biology. HRL hopes to improve its chips by enabling the silicon neurons to regulate their own firing rate as those in brains do, and IBM is wiring the connections between cores on its latest neuromorphic chip in a new way, using insights from simulations of the connections between different regions of the cortex of a macaque. Modha believes these connections could be important to higher-level brain functioning. Yet even after such improvements, these chips will still be far from the messy, complex reality of brains. It seems unlikely that microchips will ever match brains in fitting 10 billion synaptic connections into a single square centimeter, even though HRL is experimenting with a denser form of memory based on exotic devices known as memristors.

At the same time, neuromorphic designs are still far removed from most computers we have today. Perhaps it is better to recognize these chips as something entirely apart—a new, alien form of intelligence.

They may be alien, but IBM's head of research, Zachary Lemnios, predicts that we'll want to get familiar with them soon enough. Many large businesses already feel the need for a new kind of computational intelligence, he says: "The traditional approach is to add more computational capability and stronger algorithms, but that just doesn't scale, and we're seeing that." As examples, he cites Apple's Siri personal assistant and Google's self-driving cars. These technologies are not very sophisticated in how they understand the world around them, Lemnios says; Google's cars rely heavily on preloaded map data to navigate, while Siri taps into distant cloud servers for voice recognition and language processing, causing noticeable delays.

The traditional approach is to add more computational capability and stronger algorithms, but that no longer scales.

Today the cutting edge of artificial-intelligence software is a discipline known as "deep learning," embraced by Google and Facebook, among others. It involves using software to simulate networks of very basic neurons on normal computer architecture (see "10 Breakthrough Technologies: Deep Learning," May/June 2013). But that approach, which produced Google's cat-spotting software, relies on vast clusters of computers to run the simulated neural networks and feed them data. Neuromorphic machines should allow such faculties to be packaged into compact, efficient devices for situations in which it's impractical to connect to a distant data center. IBM is already talking with clients interested in using neuromorphic systems. Security video processing and financial fraud prediction are at the front of the line, as both require complex learning and real-time pattern recognition.

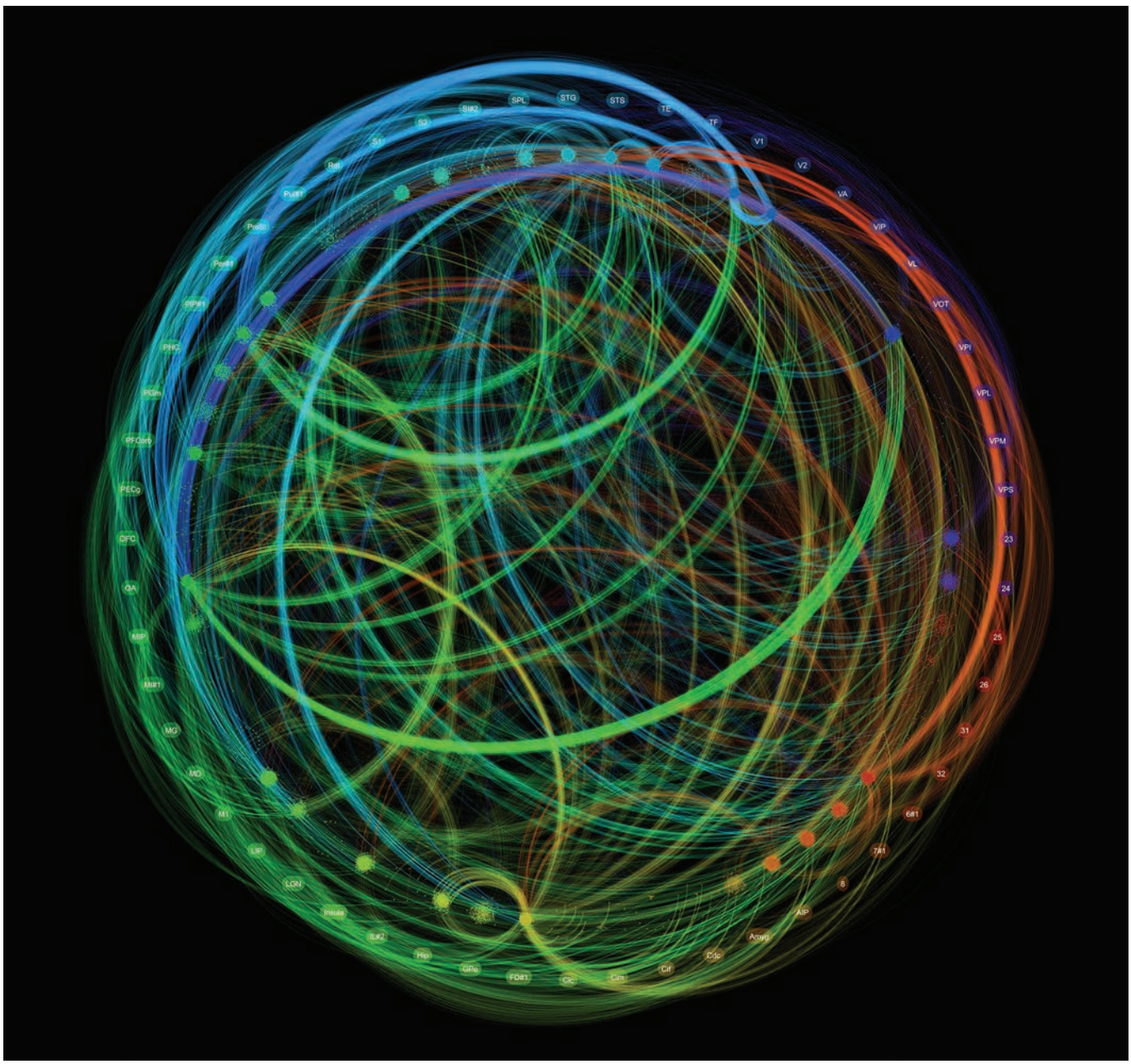
Whenever and however neuromorphic chips are finally used, it will most likely be in collaboration with von Neumann machines. Numbers will still need to be crunched, and even in systems faced with problems such as analyzing images, it will be easier and more efficient to have a conventional computer in command. Neuromorphic chips could then be used for particular tasks, just as a brain relies on different regions specialized to perform different jobs.

As has usually been the case throughout the history of computing, the first such systems will probably be deployed in the service of the U.S. military. "It's not mystical or magical," Gill Pratt, who manages the Synapse project at DARPA, says of neuromorphic computing. "It's an architectural difference that leads to a different trade-off between energy and performance." Pratt says that UAVs, in particular, could use the approach. Neuromorphic chips could recognize landmarks or targets without the bulky data transfers and powerful conventional computers now needed to process imagery. "Rather than sending video of a bunch of guys, it would say, 'There's a person in each of these positions—it looks like they're running,'" he says.

This vision of a new kind of computer chip is one that both Mead and von Neumann would surely recognize. T

Tom Simonite is senior IT editor at MIT Technology Review.

COURTESY OF DARPA



IBM used this simulation of long-range neural pathways in a macaque monkey to guide the design of neuromorphic chips.

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BUSINESS REPORT

Beyond the Checkout Cart

Here's why mobile phones, social networks, and in-store tracking are blurring the difference between online and offline retail.

CONTENTS

Read the full report online at technologyreview.com/business

LUCA MAININI

The Big Question

It's All E-Commerce Now

Thinking of e-commerce as a separate category no longer makes sense.

● When you think of Macy's, you probably picture Santa Claus, a Thanksgiving Day parade, or its 11-story, 2.2-million-square-foot flagship location in Manhattan, once known as the world's largest store.

But that wouldn't be an accurate picture of the U.S. retailer. In recent years, Macy's has turned into a digital hybrid nearly as familiar with GPS signals and online advertising as it is with clothes racks and perfume counters. According to its annual report, it's now "an omnichannel retail organization operating stores and websites."

"Omnichannel" is a buzzword that describes a survival strategy. Threatened by the growth of low-cost online merchants, traditional retailers are reacting by following customers onto the Internet. Macy's does it as well as any. On its website, it installs 24 different tracking cookies on a visitor's browser. On TV, it runs ads with Justin Bieber that urge millennials to download its mobile app, which tells them which of the chain's stores is closest to their location. Once inside, they can use the app to scan a QR code on a pillowcase or a pair of shoes. Online →

orders now ship from the back rooms of 500 Macy's stores that this year began acting as mini distribution centers.

So what's online and what's offline? And does it matter anymore in retail? These are the big questions behind this month's *MIT Technology Review* Business Report. "Getting into data, analytics, or mobile isn't even a decision anymore, so we should stop calling it e-commerce and call it just commerce, or maybe pervasive commerce," says Chris Fletcher, a research director at Gartner who works with retailers. "It's happening and you have to deal with it. But companies are just getting used to the idea that it's all one experience."

80%
of store shoppers check prices online

According to the U.S. Census Bureau, which tracks economic data, only 5.7 percent of U.S. retail purchases were made online in 2012 (13.1 percent if you don't include gasoline, groceries, or automobiles). So in-person sales still dominate. But these figures underestimate the effect of the Internet. When stores like Best Buy survey their customers, they find that 80 percent of them have already searched for price information online. A third of them do so while on a phone inside a store.

Coloring the situation is just how badly most large merchants misjudged technology. Back in 2008, Accenture found that retailers invested only 2 percent of their revenue in technology while most other industries invested two to three times that much. As they stood by, Amazon.com amassed annual sales of $60 billion, six times the online sales of its nearest U.S. competitor, Walmart.

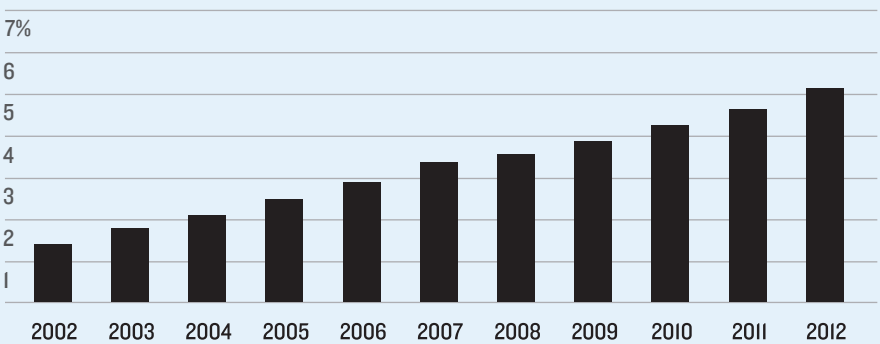
With its thousands of engineers, Amazon is starting to look like a software company that just coincidentally sells things. But now it and other Internet companies, including eBay and Google, are investing in same-day delivery—getting goods to people just hours after they order them. With their drop boxes and fleets of delivery cars, they're bidding to eliminate one of physical retailers' main advantages: immediate gratification.

Traditional chains are running in the opposite direction. They must reach customers on social media, on the Web, and on their phones. But their stores—often thought of as a costly liability—may turn into an surprising advantage. One emerging technology is indoor mapping, which enables retailers to capture customers' cellphone locations while they're browsing. With Wi-Fi sensors and even video surveillance, chains may be able to do the same kind of behavioral advertising that's possible on the Web. Imagine them, for instance, sending a timely coupon to that shopper circling the outdoor grills in Aisle 6.

"Retail has become a blur. And the blurring is 100 percent driven by technology," says Tige Savage, a partner at AOL founder Steve Case's investment company Revolution Ventures, which is investing in new retail startups. "Are you at the store? Or is the store at you? And then there's mobile—the store is in your pocket. The game is to satisfy demand wherever and whenever it is."

—Antonio Regalado

Online Shopping's Steady Play
Percentage of U.S. retail revenues from online purchases



SOURCE: U.S. CENSUS BUREAU

Leaders

The Internet Killed Distance. Mobile Phones Brought It Back.

Here's why location matters again in e-commerce.

● For retailing, the key change produced by the Internet is that shopping online spared consumers the economic costs (in time, grief, and gas money) of visiting a store and locating a product. This has been called the "death of distance." When even isolated individuals can buy anything from a global marketplace, physical location does not confer any commercial advantage, and online merchants might be expected to win every battle.

But an emerging body of economic research shows that there is no independent "online world." Physical context matters to e-commerce. It shapes our choices and tastes, and it strongly determines what we buy online. With the rise of mobile computing, these local effects matter even more.

Given how easy it is to find and buy books, electronics, and other items online, why do people continue to buy in stores at all? The reason is that online buying generates what economists call disutility: inspecting digital products is difficult, shipping can be slow or expensive, and returning products can be challenging.

Research shows that people weigh these disadvantages against the benefits of buying online. Along with colleagues Chris Forman and Anindya Ghose, I

examined what happened to Amazon's book sales in 1,497 locations in the United States when a Walmart or Barnes & Noble opened nearby. We found that customers who lived near the newly opened stores bought many fewer best-sellers from Amazon.

This means that for mainstream products, local retail options—the offline world—had large economic effects on online business. The physical environment shapes online behavior in other powerful ways. Neighbors tend to like the same music, books, and cars. Social networks are also local. Most e-mail a person receives comes from the same city, often from the same building. So even though we speak of the Internet as a "place" where users "visit" websites, this metaphor falls flat when we consider actual behavior. All online behavior has an offline context.

Mobile computing strengthens the links between online and offline life. Before, online activity happened in a specific place, sitting at a desk. Now smartphones mean that wherever consumers happen to be, they can gather information online, compare prices, or buy something. Brick-and-mortar stores worry that customers might be browsing products in their aisles but buying online.

Yet the offline environment is actually more important when consumers connect through a mobile device. With colleagues including Sang Pil Han of the City University of Hong Kong, I studied 260 users of a South Korean microblogging service similar to Twitter. What we found was that behavior on the small mobile screen was different from behavior on the PC. Searching became harder to do, meaning that people clicked on the top links more often. The local environment was also more important. Ads for stores in close proximity to a user's home were more likely to be viewed. For every mile closer a store was, smartphone users were 23 percent more likely to click on an ad. When they were on a PC, they were only 12 percent more likely to click on close-by stores.

Thus the mobile Internet is less "Internetlike" than Web browsing on a PC: search costs are higher and distance matters more. We do not yet know how the growth of the mobile Internet will affect the balance between online and offline retailers. But it appears certain that physical-world stores will do better if they can leverage the information available online, and that online retailers will need to understand their customers' offline environment in order to succeed.

Avi Goldfarb is a professor of marketing at the University of Toronto's Rotman School of Management.

Emerged Technologies

Same-Day Delivery: Can It Succeed This Time?

For $5, Google delivered candy, hot sauce, and socks to my doorstep.

● The couriers delivered the packages one by one to my San Francisco office on Halloween. First came the bag of jelly beans, followed by candy corn, then a bottle of sparkling lemonade—each in a crisp white bag decorated with a hot-air balloon—and finally a pack of bubble gum, tucked neatly into a matching plastic envelope.

I had ordered the goodies from Google Shopping Express, the same-day delivery service launched in San Francisco in September. My goal: to understand why Internet companies are again spending millions to deliver just about anything inside a couple of hours.

Besides Google, I could have ordered from Amazon, eBay, or a slew of start-ups like Postmates and Instacart. All are spending lavishly on speedy-delivery necessities like couriers, delivery vans, fulfillment centers, and advertising in a way that brings to mind the heady days of the dot-com boom, when Internet investors poured millions into delivery companies like WebVan and Kozmo.com.

Those companies eventually went belly up. But consumer habits and expectations have changed. Technology companies seem to think local delivery will finally be sustainable—or perhaps just strategically useful. Online retail is growing fast, and delivering things more quickly is one way to stand out.

"Everything in retail revolves on price and availability," says Jeremy Levine, a venture capitalist at Bessemer Venture Partners. "Price is price, and availability is a measure of how fast I get it after I click on my phone. A lot of the big guys are trying to crack that code."

It did feel a bit like trick-or-treating to press Buy on Google's Shopping Express app and then have a delivery person show up with my purchases less than two hours later. Google actually sends couriers to stores including Whole Foods, Target, and Walgreens to pick up the items. The delivery price is $5 for each store they pick up from, although Google is waiving the fees for the first six months.

The process had some glitches. I had to wait around because my four orders were delivered by four separate Google couriers. But Google's phone app gives some clues as to the company's strategy. It offers a column called "Reorder Your Essentials" (in my case, candy, hot sauce, and ibuprofen). The idea is that you would stop going to the store.

During the heady days of the dot-com boom, Internet investors poured millions into delivery companies like WebVan and Kozmo.com, only to see them fail.

Not everyone is convinced. "Is this really something people want?" wonders

David Bell, a marketing professor at the University of Pennsylvania. He thinks the rush toward same-day delivery might be less a great business idea than a by-product of furious competition between wealthy Internet companies. As more states charge sales tax on online orders, he notes, Web retailers need new ways to set themselves apart.

I also tested eBay Now, a year-old local delivery service that promises one-hour delivery in New York, San Francisco, and Chicago as part of eBay's plan to revamp its image from fusty auction site for vintage goods into handy source for new products. Deborah Sharkey, an eBay vice president, told me the company intends to expand same-day shipping to 25 more U.S. cities in an effort to make the service "the most convenient way" to get just about any item. Unlike Google, eBay encourages larger purchases because it has a $25 minimum. I was considering buying a cheap iPhone case using the eBay Now app, but I ended up splurging on a $40 Orla Kiely–designed case from Best Buy. It came in about an hour, delivered by a cheerful female messenger, or what eBay calls a "valet."

One reason online commerce hasn't yet wiped out American malls is that shopping is a form of entertainment. It's something to do. But I found that technology can also make shopping fun. Once you place an order on eBay's app, you can track the progress of your valet. You can even call the valet, as I did to check on the sizing for two pairs of cashmere socks I purchased from Macy's.

I also tested returning items, like the socks, which I discovered were not 100 percent cashmere. It proved easy: I sent an e-mail to eBay Now and was asked to provide my contact information and preferred pickup time and location. Another valet arrived promptly at the suggested time and whisked away my socks.

I think eBay probably lost money on that order. Building a delivery service is enormously expensive and challenging, because of the capital costs of warehouses and delivery fleets. To be profitable, delivery services need not only a lot of customers but ones who keep coming back. And that's where same-day delivery might fall down. It was nice to have such convenient shopping experiences. But I wasn't clamoring for the service in the first place. The two-day delivery I get as a member of Amazon's Prime shipping service (free once you've paid to join) is generally fast enough, and I would miss my weekly trip to the supermarket.

I found that technology can make shopping fun. Once you place an order on eBay's app, you can track the progress of your "valet."

I don't think I'm alone. Research by Sucharita Mulpuru of Forrester has found that there's something consumers consistently prefer over fast shipping: free shipping. *—Rachel Metz*

Tomorrow's Just Fine

Percentage of U.S. consumers saying online shopping could be most improved by the following:

SOURCE: BCG SURVEY OF 1,000 U.S. CONSUMERS

Emerged Technologies

By Sniffing Out Phones, Stores Follow Visitors

Indoor location technology brings Internet-style tracking to physical spaces.

● You've just tossed a jar of peanut butter in your grocery cart when your smartphone buzzes. You glance at the screen to see a message that seems downright clairvoyant: Buy some jelly. Get $1 off.

Convenient? Certainly. Creepy? Maybe.

This is one vision for indoor positioning, a fast-evolving technology that is allowing retailers to track shoppers' physical movements along their aisles in unprecedented detail. In many big-box stores, equipment is already in place to sniff out customers' smartphones and log data such as how many minutes a person spends in the shoe department.

The technology could eventually give retailers capabilities rivaling those of online stores. On the Web, behavioral ads use records of a person's browsing history to propose products. Now pharmacies or home improvement stores wanting to sell Kleenex or two-by-fours could soon do the same thing.

"Not much is known about what shoppers do in stores until they check out at the cashier," says Todd Sherman, chief marketing officer for Point Inside, a startup in Bellevue, Washington, one of a score of companies that have raised venture capital funding to perfect indoor tracking and advertising techniques. "This way, you can see what they're interested in [and] see where they're going."

U.S. retailers including Nordstrom, Family Dollar, and American Apparel have experimented with indoor positioning. Some systems use video cameras, sound waves, or even magnetic fields. In

September, Apple added a feature called iBeacon to its smartphones that emits a low-power Bluetooth radio signal, also designed for indoor use.

The most widely used technique is to intercept Wi-Fi signals emitted by shoppers' smartphones. Triangulating on that signal can estimate the phone's position to a few meters. Stores also collect a unique identifier for each phone, called a MAC address. That allows them to build up behavioral information on return visitors.

Forest City Enterprises uses cellular signals to monitor foot traffic in most of the nearly 20 shopping centers it owns or manages. It says the data helped it decide where to move an escalator that was interfering with an entrance. The company also measures how long visitors stay after a fashion show or concert. Stephanie Shriver-Engdahl, Forest City's vice president of digital strategy, says the company wants to answer questions like "Do they get one soda, hop in the car, and leave? Or are they staying longer?" In the future, foot-traffic data could be used to set lease prices, she says.

Because indoor tracking is still complex, it may not take off the way some proponents expect. "Simply because the technology exists and it's possible doesn't mean that marketers will do it," says Greg Sterling, an analyst with Opus Research. "Some of this stuff may never happen."

But Don Dodge, a Google executive who has invested in several indoor location companies, believes the technology will be "bigger than GPS" or online maps. That's because people spend most of their time indoors, he says, where GPS signals are often too weak to be useful.

Google has already expanded its maps to include diagrams of the inside of museums, airports, and large stores in 17 countries, like Hong Kong's Tai Po Mega Mall. The company appears to think indoor maps will gain importance once it begins selling its head-mounted computer, Glass. "Indoor location is going to be huge," Dodge says. "It's going to be the biggest thing to hit retailing and couponing that we've ever seen."

Before that happens, retailers may have to brave a privacy debate. Nordstrom suffered a public relations black eye this year after it began tracking customers in 17 stores using a Wi-Fi system developed by Euclid Analytics. Some customers who read signs at store entrances explaining the technology complained about an invasion of their privacy.

Nordstrom says it ended the test a few months ago. "Basically, it had run its course. We learned some things and we moved on," says Colin Johnson, a Nordstrom spokesman. "At the same time, we recognize that we have to continue to test and try new things in order to evolve and stay relevant to the customer."

Since the Nordstrom episode, retailers have become reluctant to acknowledge their use of indoor tracking. But RetailNext, a company offering "comprehensive in-store analytics," says its products are being used by 100 large retailers and in thousands of stores. Euclid also says it has 100 customers, including Home Depot. *—Verne Kopytoff*

Indoor Positioning

Technologies to track shoppers, and the startups developing them

WI-FI TRIANGULATION
Consumers' smartphones emit radio signals and unique identifiers.
EKAHAU, WIFISLAM

RADIO BEACONS
Low-power radios located in buildings communicate with phones.
BLINKSIGHT, INSITEO

LED LIGHTS
Beacons emit invisible light pulses to communicate their position to smartphone cameras.
BYTELIGHT

MAGNETISM MAPS
A smartphone's internal compass senses unique magnetic distortions inside stores.
INDOOR ATLAS, INDOO.RS

SENSOR TRACKING
Starting with a known location, a phone's gyroscope, accelerometer, and compass can reckon a shopper's position.
AISLE411, EVERYFIT, POINTINSIDE

Case Studies

Best Buy Battles Back Online

The world's largest electronics retailer thinks stores are an asset in the fight with online merchants.

● After Best Buy lost $1.2 billion during 2012, the world's largest consumer electronics retailer looked as if it was headed toward the same discontinued-item bin as onetime rival Circuit City, which went bankrupt four years earlier.

The problem was the Internet. Customers were comparison shopping and finding lower prices online. Sometimes they checked from a smartphone right in the aisles of a Best Buy store after sizing up the real merchandise. Analysts predicted that the phenomenon, dubbed "showrooming," could destroy Best Buy.

That's not what happened—not yet, anyway. Instead, Best Buy is making money again, and its stock has tripled in value. It has managed to repair its online stores and to tie its online presence more tightly to its network of 1,400 locations, in ways that it thinks may have neutralized the showrooming threat. Its president of e-commerce, Scott Durchslag, even taunts Amazon by saying that "stores are the greatest showroom on Earth."

Best Buy's turnaround effort started after a boardroom drama that saw its CEO and chairman resign. Its new CEO, Hubert Joly, arrived in late 2012 and quickly issued a five-point manifesto to revamp the brand, known as "Renew Blue." Best Buy sold off its European stores, trimmed its staff, and promised to revive its sales using a strategy called "omnichannel" retailing.

The idea in omnichannel is to reach customers wherever they are—in a store, online, or on their phones—and use technology to turn costly physical stores into an advantage. One deceptively simple step Best Buy took was to add a "Pick Up in

Store" button to its online store. It turns out many shoppers like to browse and pay online but prefer to actually pick up that TV themselves—they just had no way of doing it before.

As he later told investors, when Durchslag got to Best Buy in October 2012 (he'd previously worked at Expedia, the travel booking site), the chain's website was in "a 10-year time warp." It didn't have on-site recommendations, prices didn't match those in its store, and it took eight clicks to buy anything. Its rewards program and well-known support desk team, the Geek Squad, had their own databases that didn't talk to one another.

That was a problem. About 25 percent of all consumer electronics sales take place online. But Best Buy hadn't kept up. Online sales are still only about 6 percent of its revenues.

Best Buy has since made more than 200 changes to its online store. The number of clicks to make a purchase has been cut to three, and now Best Buy takes into account where people live, serving up, say, air-conditioner specials to New Yorkers who log on during a heat wave.

Another problem to fix was that Best Buy was operating its online division and

$1.2 billion
Money lost by Best Buy in 2012

stores separately. Durchslag says that previously, if Best Buy's online distribution center was out of an item, the customer would simply get an out-of-stock notice. They were losing those customers even though Best Buy stocked similar inventory at its stores, one of which is no more than a 15-minute drive from 70 percent of the U.S. population.

Best Buy has since begun testing whether it can increase its inventory by turning stores into distribution centers. Having started with 50 stores, it is adding inventories from 150 more stores to its website for the 2013 holidays.

Durchslag says retailers are still trying to understand consumers' new behaviors. He says that since the "Pick Up in Store" button was added to its online shop, 40 percent of shoppers on Bestbuy.com have chosen that option. No one could have predicted that, because no one had tried it before. "When it comes to omnichannel innovation," says Durchslag, "I don't think anybody's doing it really, really well, especially for consumer electronics."

—Michael Fitzgerald

Case Studies

No Stores? No Salesmen? No Profit? No Problem for Amazon.

Its massive investments in technology shape the future for all retailers.

● Why do some stores succeed while others fail?

Retailers constantly struggle with this question, battling one another in ways that change with each generation. In the late 1800s, architects ruled. Successful merchants like Marshall Field created palaces of commerce so gorgeous that shoppers rushed to come inside. In the early 1900s, mail order became the "killer app," with Sears Roebuck leading the way. Toward the end of the 20th century, ultra-efficient suburban discounters like Target and Walmart conquered all.

Now the tussles are fiercest in online retailing, where it's hard to tell if anyone is winning. Retailers as big as Walmart and as small as Tweezerman all maintain their own websites, catering to an explosion of customer demand. Retail e-commerce sales expanded 15 percent in the U.S in 2012—seven times as fast as traditional retail. But price competition is relentless, and profit margins are thin to nonexistent. It's easy to regard this $186 billion market as a poisoned prize: too big to ignore, too treacherous to pursue.

Even the most successful online retailer of all, Amazon, has a business model that leaves many people scratching their heads. Amazon is on track to ring up $75 billion in worldwide sales this year. Yet it often operates in the red; last quarter, it posted a $41 million loss. Amazon's founder and chief executive officer, Jeff Bezos, is indifferent to short-term earnings, having once quipped that when the company achieved profitability for a brief stretch in 1995, "it was probably a mistake."

Look more closely at Bezos's company, though, and its strategy becomes clear. Amazon is constantly plowing cash back into its business. Its secretive advanced-research division, Lab 126, works on next-generation Kindles and other mobile devices. More broadly, Amazon spends heavily to create the most advanced warehouses, the smoothest customer-service channels, and other features that help it grab an ever larger share of the market. As former Amazon manager Eugene Wei wrote in a recent blog post, "Amazon's core business model does generate a profit with most every transaction … The reason it isn't showing a profit is because it's under-

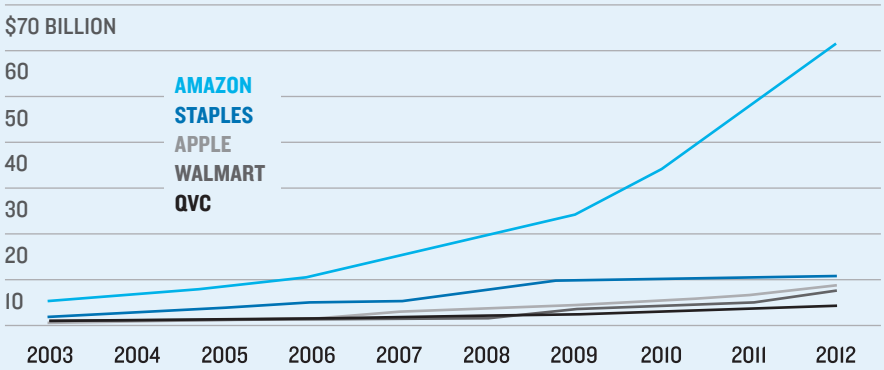
Price competition is so relentless that it's easy to regard e-commerce as a poisoned prize: too big to ignore, too treacherous to pursue.

taken a massive investment to support an even larger sales base."

Much of that investment goes straight into technology. To Amazon, retailing looks like a giant engineering problem. Algorithms define everything from the best way to arrange a digital storefront to the optimal way of shipping a pack-

Amazon Jumps Ahead

Amazon's revenues outpace the online sales of the next-largest Internet retailers in the U.S.



age. Other big retailers spend heavily on advertising and hire a few hundred engineers to keep systems running. Amazon prefers a puny ad budget and a payroll packed with thousands of engineering graduates from the likes of MIT, Carnegie Mellon, and Caltech.

Other big merchants are getting the message. Two years ago Walmart, the world's largest retailer, opened an R&D center in Silicon Valley where it develops its own search engines and looks for startups to buy. But competing on Amazon's terms doesn't stop with putting up a digital storefront or creating a mobile app. Walmart has gone as far as admitting that it may have to rethink what its stores are for. To equal Amazon's flawless delivery, this year it even floated the idea of recruiting shoppers out of its aisles to play courier, whisking goods to customers who've ordered online.

Amazon is a tech innovator by necessity, too. The company lacks three of conventional retailing's most basic elements: a showroom where customers can touch the wares; on-the-spot salespeople who can woo shoppers; and the means for customers to take possession of their goods the instant a sale is complete. In one sense, everything that Amazon's engineers create is meant to make these fundamental deficits vanish from sight.

Amazon's cunning can be seen in the company's growing patent portfolio. Since 1994, Amazon.com and a subsidiary, Amazon Technologies, have won 1,263 patents. (By contrast, Walmart has just 53.) Each Amazon invention is meant to make shopping on the site a little easier or a little more seductive, or to trim away costs.

Consider U.S. Patent No. 8,261,983, on "generating customized packaging," which came into being in late 2012. "We constantly try to drive down the percentage of air that goes into a shipment," explains Dave Clark, the Amazon vice president who oversees the company's

1,263
Patents won by Amazon

nearly 100 warehouses, known as fulfillment centers. The idea of shipping goods in a needlessly bulky box (and paying a few extra cents to UPS or other carriers) makes him shudder. Ship nearly a billion packages a year and those pennies add up.

Amazon has created more than 40 sizes of boxes over the years—but even that isn't enough. That's the glory of the packaging patent: when a customer's odd pairing of items creates a one-of-a-kind shipment, Amazon now has systems that will compute the best way to pack that order and create a perfect box for it within 30 minutes.

For thousands of online merchants, it's easier to live within Amazon's ecosystem than to compete. So small retailers such as EasyLunchboxes.com have moved their inventory into Amazon's warehouses, where they pay a commission on each sale for shipping and other services. That is becoming a highly lucrative business for Amazon, says Goldman Sachs analyst Heath Terry. He predicts Amazon will reap $3.5 billion in cash flow from its third-party shipping services in 2014, creating a very profitable side business that he values at $38 billion—about 20 percent of the company's market value.

Jousting directly with Amazon is tougher. Researchers at Internet Retailer calculate that Amazon's revenue exceeds that of its next 12 competitors combined. In a regulatory filing in 2013, Target—the third-largest U.S. retailer—conceded that its "digital sales represented an immaterial amount of total sales." For other online entrants, the most prudent strategies generally involve focusing on areas that the big guy hasn't conquered yet, such as services, online "flash sales" that snare impulse buyers who can't pass up a deal, or particularly challenging categories such as groceries. Yet many, if not most, of these upstarts are losing money.

Confronted with today's profitless hypergrowth, Amazon's inventors are hard at work on that problem as well. The company's basic patents for "buy this, too" recommendations—which date back to 2000—have been supplemented in the past two years with nearly a dozen additional ideas for enticing visitors to put some extra gear into their carts. One twist: suggesting to online shoppers just the right $5.98 paperback to help them inch past the threshold that qualifies for free shipping.

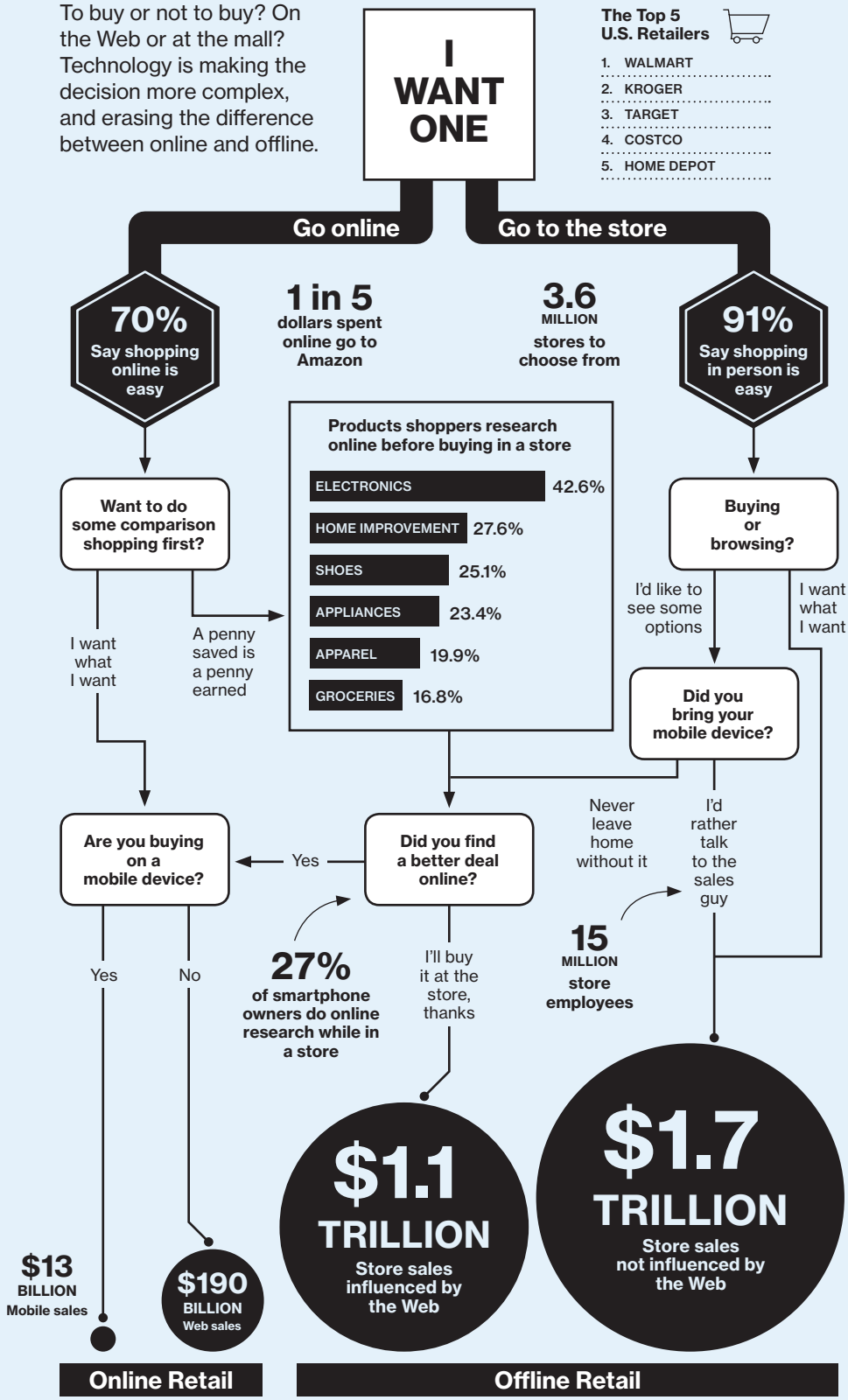
Clerks in physical stores have been upselling for ages through classic questions such as "Would you like a tie to go with that suit?" But in Amazon's round-the-clock digital emporium, it's possible to target customers' shopping carts with a game theorist's precision. Weeks before the 2013 holiday shopping season got rolling, for example, Amazon announced that a $25 order wasn't quite big enough anymore to qualify for free shipping. The new minimum: $35.

—George Anders

SOURCES: INTERNET RETAILER, WALL STREET JOURNAL

The Shopping Decision Tree

To buy or not to buy? On the Web or at the mall? Technology is making the decision more complex, and erasing the difference between online and offline.



All data for U.S. retail.

SOURCES: ACCENTURE, FORRESTER, NRF, SHOPORG

Leaders

Q/A Steve Case

The man who brought the Internet to Main Street wants everyone to open an online store.

● You might remember Steve Case. He was CEO of America Online and became a billionaire selling subscription Internet access. Now Case, 55, runs a $700 million venture capital fund, Revolution, that has been investing in e-commerce companies.

E-commerce is less than 6 percent of retail sales. Has it moved slowly?
In some categories e-commerce has been disruptive; a lot of bookstores have gone out of business. But malls are doing pretty well, because shopping is fundamentally a social experience; it's not just about buying things. [Yet] the trajectory of e-commerce is that it's just going to continue to grow.

Where do you see the growth?
There are something like 10 million independent e-commerce merchants on places like eBay and Etsy. There is a lot more opportunity for a lot of folks to hang up their shingle digitally and play a role.

What's your biggest investment?
We have invested pretty heavily [$40 million] in BigCommerce, which essentially has the power of Amazon's e-commerce tools that you can set up in minutes. Five years ago, you'd have spent six months and hundreds of thousands of dollars to build an e-commerce site. Now you can do it in 30 minutes for 30 bucks. I think that is pretty cool. It completely democratizes e-commerce for everybody. It's been hard up until now for small companies to play.

—Antonio Regalado

Innovations and News from Moscow Forum

In Moscow, Opening the Door to Innovation

OPEN INNOVATIONS
Forum and Exhibition

A trio of prime ministers, the visionary who helped send the first civilians to space, and an empathetic and chatty robot who helps people stick to their diets were among those sharing the stage at Open Innovations, an annual gathering in Moscow that brings together some of the world's top experts in disruptive change and technology.

During the two-day event, leaders shaping global development – policy makers, academics, entrepreneurs, designers, and technologists – delved into today's most game-changing innovations and worked to unpack the puzzle of how entrepreneurship can best be driven forward, from Big Data healthcare applications to driverless robotic cars, 3-D printing, nanotechnology, and more.

"Consumers will be the big winners in all of this, but we will have to think hard how this affects industry," said James Manyika, director of McKinsey Global Institute. "No industry will be safe from disruption. Policies and rules will have a hard time keeping up, but they must keep up."

ITAR-TASS

The combination conference and exposition was hosted by the Moscow International Forum for Innovative Development, a consortium of investors and technology and policy experts dedicated to moving innovation ahead in Russia. Over 4,000 people from 47 countries attended the Forum in 2013, crowding into more than 70 lively sessions, discussions, roundtables, and lectures. More than 12,000 people visited the accompanying Open Innovations Expo 2013, where some 1,000 new technological developments were on display, many of them Russian, ranging from a robot playmate for children to medical devices that track and organize individual patient data.

"Moscow is open for innovative business," said Moscow's mayor, Sergei Sobyanin, in his welcoming remarks. "We have a new startup generation ... a new generation of youth here," he said, describing a vibrant and expanding network of technology and business incubators, startups, and venture capital investment opportunities in Moscow.

The Forum focused on game-changing technologies and innovations that will be setting the agenda for coming decades. Top people and players shaping key emerging sectors, including artificial intelligence, cloud computing, and 3-D printing, urged participants to harness innovation to push boundaries, both to keep their countries and companies competitive and to solve tough public problems. "Crowdsourcing genius" was one suggestion offered to harness talent and answers.

Galvanizing the audience was effervescent keynote speaker Peter Diamandis, co-founder and chairman of Singularity University and founder of the X PRIZE Foundation, who has been closely involved in the Russian space program. "I believe there is no problem we cannot solve over the next 20 to 30 years," Diamandis said. "A combination of technology, passion, and capital is making it literally possible to solve all our problems."

In contrast to most of human history, in which humanity's challenges have been local and linear, said Diamandis, "today we are living in a world that is global and exponential." Diamandis cited the example of Kodak, which failed to grasp the potential exponential growth and reach of digital photography. "Kodak was put out of business with the very technology they created." In 2012, the year Kodak went bankrupt, Instagram, then a company of 13 people, was acquired for $1 billion.

According to Diamandis's calculations, the average lifespan of a company has shrunk from 67 years to 15. "The rate of innovation and disruption is skyrocketing," he said. "The rule is, if you do not disrupt yourself, the business world will."

Mikhail Pogosyan, president of United Aircraft Corporation, a major Russian aircraft construction company, said that even in the post-Soviet era, as the military industry collapsed, his company's work in aviation proved resilient. "We are a market leader standing on our feet because our projects are innovative," he said, noting his company's annual growth rate of 18 percent. "Our objective is to become a world leader by not just creating airplanes but creating the kind of environment needed to make changes, to constantly adapt ourselves to market demands."

ITAR-TASS

French prime minister Jean-Marc Ayrault in the seat of a vehicle at the expo, surrounded by Russian prime minister Dmitry Medvedev, Finnish prime minister Jyrki Katainen, and others

Three Prime Ministers

A session titled "Proven State Leadership Strategies in a Hyper-Connected World" brought together Dmitry Medvedev, the prime minister of the Russian Federation, and his French and Finnish counterparts, Jean-Marc Ayrault and Jyrki Katainen, to discuss how the state can best encourage innovation.

"In Russia we have not been able to do this indirectly, so we have been doing so directly," said Medvedev. "I'd like to see us reach the day when everything is shaped by market demand ... where the active participation of the state is no longer needed."

In the meantime, said Medvedev, Russia has an ambitious and strategic plan to foster an ecosystem for innovation, including developing and supporting young entrepreneurs by bringing them together in incubators to develop products and ideas.

"We have invested greatly in infrastructure, hundreds of billions of rubles, but it's important that we are specific as possible in our intentions," said Medvedev. "We are seeking commercially viable projects, and entrepreneurs will be able to find support."

Medvedev spoke of Russia's plans to reach significant milestones in developing an innovation economy in the coming years. "We expect that, from 2015, [our development strategy] will allow innovation to add around one percentage point to our economic growth," said Medvedev. "This is of course an ambitious target, but we still count on it happening."

Ayrault said that although it can be tricky to intervene, governments can play a role in supporting and nudging progress along through tools like tax incentives.

Finland's Katainen described how his country is investing in accelerators in universities to speed up research and the innovations that bring new jobs. "In my country, we believe our future will depend less on a few leading companies and more on widespread entrepreneurial activities," said Katainen.

The leaders also discussed the global environmental changes that countries are facing, suggesting governments have an important role to play.

Noting the value of events like Open Innovations, where people meet and "maybe create something new," Ayrault described large-scale projects, including a "high-speed train of the future" and a new generation of electric planes. "In the 21st century, the new word is openness, because the technological challenges are so immense," he said.

"I believe international cooperation is important, including joint cooperation between our countries," Ayrault said, referring to France and Russia, in sectors such as aviation and rockets.

"Let's measure up to this watershed moment," said Medvedev, noting the opportunities ahead.

The Game-Changers

The Forum focused both on people and on game-changing products, devices, and tools at a time when demand for innovation entrepreneurship is skyrocketing. Speakers exchanged ideas about how to become and remain competitive, including giving new ventures space to nurture their ideas and "blossom" before evaluating their potential.

Gerald Schotman, executive vice president of innovation and R&D and chief technology officer of Royal Dutch Shell, described how his industry has been forced to innovate as it has faced a global surge in demand for energy. "Ultimately innovation is about getting out of one's comfort zone and really embracing the unknown."

The Forum focused both on people and on game-changing products, devices, and tools at a time when demand for innovation entrepreneurship is skyrocketing.

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Open Innovations Expo: Young innovators worked together in the InnoKids lab to create a 3D layout for the city of the future

OPEN INNOVATIONS' FORUM ARCHIVE

At the Expo, a young attendee plays with Kolobok's small robot designed for children

CATHERINE WALES

3-D printing technology can contribute to sustainability in fashion

Over 12,000 people visited the accompanying Open Innovations Expo 2013, where some 1,000 new technological developments were on display, many of them Russian.

Time was also dedicated to recognizing what good leadership in the world of innovation and entrepreneurship looks like. One definition of leadership, borrowed from MIT's Sloan School of Business, was offered in a panel discussion titled "Education for the 21st Century": leadership is "relating to others, creating visions, making sense of situations, and delivering on visions."

Take-Aways:

Game-changers in the 21st century will be individuals who:

- Have the freedom to pursue new ideas
- Are willing to take big risks
- Collaborate with international partners
- Identify and understand their customers in depth, and craft their product or services accordingly
- Focus on one market

"We need to innovate the way we innovate," said Gerald Schotman, executive vice president of innovation and R&D and chief technology officer of Royal Dutch Shell.

The conference explored how hyper-connectivity is transforming the way we live and work and changing barriers to participation. Jason Pontin, editor-in-chief and publisher of MIT Technology Review, addressed this topic directly in his introduction of a report prepared for the conference, Emerging Trends Report 2013, a guide for policy makers, science educators, funders, and entrepreneurs detailing some of the most transformational game-changing innovations across large market sectors.

"In a hyper-connected world, the innovations of a country's entrepreneurs and innovators are its main competitive advantage," Pontin said.

Megatrends reflected in the report included:

- Nanotechnology as a critical tool, from electronics to high-performance coatings
- How mobile devices, Big Data, and the "Internet of things" are driving sectors such as education, healthcare, and retail
- The 21st-century factory, employing tools like 3-D printing, mass customization, and cheaper, safer, and more advanced robots
- The power of the consumer in the Internet age, and the ways companies are tracking what customers really want

Addressing the conference on the final day were:

• Cory Kidd, founder and CEO of Intuitive Automata, who introduced "Autumn," a foot-tall robotic weight-loss coach that chats with its owner every day about nutrition, learning about its owner over time and adapting interactions accordingly.

• London fashion designer Catherine Wales, who described her mission to restructure fashion through 3-D printing, asking, "What if our clothing actually had its own DNA, and what if we could change it and morph it to our own needs?"

• Skylar Tibbits, director of MIT's Self-Assembly Lab, who presented his work on "transformable materials" that can transform themselves to meet the consumer's needs, so that, for example, "walking shoes, when we run, become running shoes ... or they expand to fit my foot size, as opposed to someone else's."

Next year, Open Innovations Forum 2014 will be held in Moscow from October 30 to November 1. We look forward to seeing you there.

Reviews

Too Much Information

Pregnant women now have an easy and risk-free way to identify genetic flaws in their fetuses. Are we prepared for the consequences?

By Amanda Schaffer

Pregnant women and their partners can already peer at an unborn child's chromosomes: with amniocentesis, they can learn about the presence or, more likely, absence of large-scale genetic defects, often gaining peace of mind. But only a small percentage of parents-to-be take the opportunity, because the procedure is invasive and uncomfortable—a large needle is inserted into the amniotic sac—and causes miscarriage in roughly one in 400 cases.

Researchers have long hoped to develop a noninvasive alternative. Ever since scientists discovered, in the 1990s, that pregnant women's blood contains substantial amounts of fetal DNA, they've theorized that they could use this genetic material to test for fetal abnormalities like an extra copy of chromosome 21, which causes Down syndrome.

That technology has now arrived. Several companies have introduced genetic tests that use blood drawn from the mother. These tests can be performed earlier in pregnancy than amniocentesis is usually done, which means that if the results suggest an abnormality, women and their partners have more time to grapple with whether to have an abortion or prepare for a child with special needs. If the results are reassuring, the cloud of anxiety dissipates sooner.

Given that the risks of having blood drawn are minimal, the tests are likely to be widely used. While today fewer than 5 percent of pregnant women undergo amniocentesis, "I think we could see 50, 60, 70, 80 percent of American pregnancies getting genetic testing," says Hank Greely, director of the Center for Law and the Biosciences at Stanford.

The catch, though, is that as the accuracy of these tests continues to improve, they will be able to detect a greater range of genetic variations, including some with murkier implications. For example, rather than indicating something with certainty, they could reveal elevated risks for certain diseases or disorders. These advances could collide with the politics of abortion and raise the ugly specter of eugenics. When, if ever, should parents terminate pregnancies on the basis of genetic results? Do we have the wisdom to direct our own evolution? And perhaps most important, are there limits to how much data parents should have—or want to have—about their children before birth?

Noninvasive prenatal screening

Corporate contenders

The first noninvasive tests to reach the market have screened for the largest-scale genetic defects—namely, abnormal numbers of chromosomes. Sequenom Laboratories, Verinata Health (part of Illumina), Ariosa Diagnostics, and Natera all offer tests that look for trisomies—an extra copy of chromosomes 13, 18, or 21, which cause Patau syndrome, Edwards syndrome, and Down syndrome, respectively. Some also identify an aberrant number of sex chromosomes. This fall, Sequenom expanded its test to encompass additional trisomies as well as selected microdeletions (in which DNA is missing), including those known to cause DiGeorge syndrome, Cri-du-chat syndrome, and Prader-Willi or Angelman syndrome. The various companies' tests range in price from less than $1,000 to almost $3,000, though they are covered by some insurance plans. So far, these offerings have not replaced amniocentesis, which remains the gold standard for accuracy. But they can be performed as early as 10 weeks into pregnancy and can help identify women who may need the more invasive test.

Companies will modify these tests to flag an increasing number of genetic conditions, including some that are quite rare. The trend is toward "detecting smaller and smaller mutations," says Jonathan Sheena, chief technology officer of Natera, who predicts that noninvasive identification of inherited single-gene diseases like cystic fibrosis, Tay-Sachs, and neurofibromatosis will soon become commercial reality. In the laboratory, meanwhile, researchers have already used noninvasive methods to sequence a whole fetal genome. In 2012, geneticist Jay Shendure's group at the University of Washington analyzed blood from the mother as well as a saliva sample from the father to reach this goal. Also in 2012, Stephen Quake's group at Stanford used a maternal blood sample alone to derive the fetal exome, which consists of the coding parts of genes. "That's pretty much the whole ball of wax," Quake told me. (Shendure and Quake are advisors to Ariosa Diagnostics and Verinata, respectively.) These laboratory efforts were not cheap: Shendure says it cost him around $50,000 to do the full genome. But they represent a clear proof of principle. And as

Illustration by Gracia Lam

the costs of sequencing continue to plummet, far more parents-to-be will potentially have access to far more genetic data about their future children.

Quake says he hopes the technology will be used to identify and manage conditions that are well defined and for which early intervention can make a difference; he points to metabolic disorders like phenylketonuria, in which children require a strict diet, and certain immune disorders that can respond to early treatment. If babies' problems can be diagnosed prenatally, he says, "you're not putting them in distress for the first few weeks" while everyone is "running around trying to figure out what is wrong." Another example is a condition called dilated cardiomyopathy, in which the heart is enlarged and weakened. This disorder can go undiagnosed until its victims find themselves short of breath or have a heart attack as teenagers or young adults. By treating them from a young age with drugs, physicians can "dramatically change outcomes," says Euan Ashley, a Stanford researcher who cofounded Personalis, a genetic screening company.

Ethical conundrums

But the moral quandaries are sure to intensify as well. If many more women receive information about genetic disorders like Down syndrome earlier in pregnancy, it's likely that the number of abortions will rise. Inevitably, some people will object to the testing technology because of their opposition to abortion, says Greely. And some current parents of children with Down syndrome will worry that if fewer people are born with the disorder, medical research and public support will start to dry up. The unease deepens with less severe disorders like Kleinfelter's syndrome, which is caused by an extra X chromosome in males. Boys with this syndrome often have few noticeable symptoms early on and may not be diagnosed until later in life, when they may experience atypical sexual development, learning difficulties, and infertility. If genetic testing identified more cases prenatally, some of those pregnancies would almost surely be terminated. Even firm supporters of abortion rights may find that thought troubling. Similarly, consider achondroplasia, which is an inherited form of dwarfism. If two parents with achondroplasia wanted a child who looked like them, "would it be wrong for them to terminate a normal-sized fetus?" Greely asks. "These are hard questions."

For now, testing for intelligence or height or other complex traits that might pique parents' curiosity appears to be far off: researchers largely seem skeptical that they will be able to predict these traits

We don't understand the extent to which our genomes relate to our health or happiness.

from an individual's genome in the foreseeable future. "We're really bad at it right now," says Shendure. "In 10 years we'll probably still be pretty bad at it."

But the underlying issue will still complicate the abortion debate: to what extent should parents be able to choose the traits of their children—and should the calculus change when the traits in question, like sex or hair color or eye color, are not directly linked to disease? For the most part, we tend to trust parents to make the right decisions for their children, but that prerogative may not be absolute, especially when it comes to nonmedical factors. We can't know how children's lives will unfold or how important a whole range of traits might turn out to be to them. We surely don't have the understanding to guide our own evolution, or even to understand the extent to which individuals' genomes

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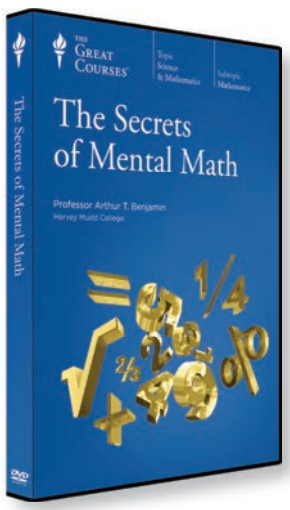

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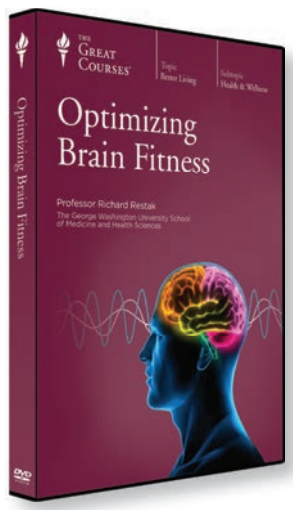

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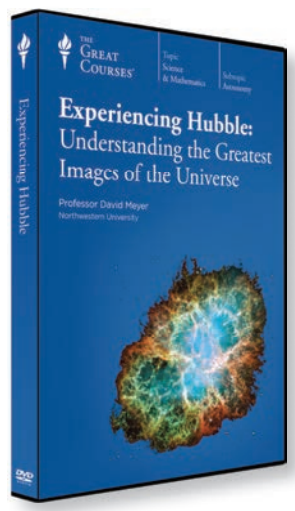

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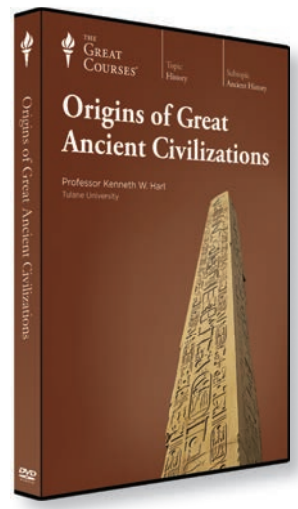

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relate to their health or happiness. And given the disastrous history of eugenics, from forced sterilizations to the Holocaust, we should maintain a healthy fear of even small-scale efforts to select some nonmedical traits over others. This is not merely a theoretical matter: parents in India, China, and South Korea who learn their fetuses' sex through ultrasound have disproportionately chosen abortion in the case of girls. (Arizona has already made it illegal to abort on the basis of sex or race, though introducing criminal penalties for doctors is not necessarily wise either.)

Perhaps the biggest question is which information will be meaningful for parents to receive. Genetic interpretation can be a dicey game. It is well known, for instance, that mutations in the BRCA1 gene are strongly associated with breast cancer, but in a disturbingly large number of cases, patients are told they have variants of unknown significance. "It would be very unfortunate if we started delivering 'variants of unknown significance' results in the context of reproductive health," Shendure says. Similarly, when it comes to complex problems like cognitive impairment, it's not clear how useful

Who knows which disorders will be curable or treatable 20 or 30 years from now?

it is to test for—or report on—variants that have been associated with disabilities. Research suggests, for instance, that people with specific duplications on chromosome 16 are at higher risk of mental impairment. Some are severely affected, but others are "absolutely, perfectly healthy, functioning normally," according to Wendy Chung, director of clinical genetics at Columbia University. To date, there is no reliable data on what percentage of duplication carriers fall into each of these categories, meaning that prenatal testing for these variants could greatly increase parents' anxiety while leaving them at a loss to assess the results quantitatively. Then there are girls with three copies of the X chromosome. They are also at higher risk for cognitive impairment and learning disabilities, but the risk remains small, and the vast majority of them will be normal. How should parents make sense of these possibilities? Most of us find it hard to think about risk, and we are truly bad at predicting how future events will affect us emotionally. And on top of all that, who knows which disorders will be curable or treatable through gene therapy or some other method 20 or 30 years from now? In other words, we're not ready for the onslaught of information the new tests seem poised to provide.

Nevertheless, that information is coming, and parents will have to figure out what they want to know and how to interpret the choices they're offered. It is critical, then, that the informed-consent process for testing be exceptionally good, says Greely. Ideally, parents should meet with a genetic counselor to discuss what exactly testing might reveal and what wrenching decisions might follow. If formal genetic counseling isn't available, obstetricians should step in with extended, thorough conversations that take into account the parents' values, desire for data, and tolerance for uncertainty. Genetic testing, as Greely puts it, should be made distinct from other forms of prenatal care; it should never be "just one more tube of blood" taken in the course of another whirlwind visit to the doctor.

Amanda Schaffer is a freelance journalist who writes about science and medicine for Slate, *the* New York Times, *and other publications.*

YAREK WASZUL

Facebook's Two Faces

The company says it wants to wire the world. But will it do more than make its own app work better?

By David Talbot

Last spring, Facebook founder Mark Zuckerberg invested in an impressive domain name: internet.org. Then, in August, he posted a video featuring snippets of John F. Kennedy's "Strategy of Peace" speech and blogged that he would "share a rough proposal for how we can connect the next 5 billion people and a rough plan to work together as an industry to get there." With that, Facebook and six corporate partners—including Nokia, Samsung, Qualcomm, and Ericsson—became part of a swelling movement of tech companies declaiming a commitment to connectivity, seemingly moved by the fact that only 2.7 billion of the world's seven billion people have Internet access. In October, Google launched the Alliance for Affordable Internet (whose members include Facebook and Ericsson). It is pushing for cheaper Internet access through policy and regulatory reforms.

Internet.org
Alliance for Affordable Internet

Behind the focus on the world's unconnected lie some complicated realities. The companies involved tend to emphasize delivering more data to people who already have network access rather than extending communications connectivity to people who have none. And despite Zuckerberg's lofty statements, Facebook in particular is falling short of some of Internet.org's goals: the company isn't investing in network extensions in developing countries, and its business practices, in many cases, have obligated Internet service providers in such places to incur extra costs.

Internet.org is still more of a press release than a plan. But its first formal statement, a 74-page white paper cosigned by base station maker Ericsson and chipset maker Qualcomm, is telling: it sets a goal of delivering data 100 times more efficiently to mobile phones, the devices most Internet newcomers will use to link to the Net.

Increasing efficiency is a perennial goal. And if it makes it possible for ISPs to offer broadband more cheaply, it could make people better off. (Research from the World Bank says that increasing broadband penetration in developing countries by 10 percent boosts their annual economic growth by 1.4 percentage points.) But getting people more data faster is quite a different objective from introducing connectivity in the first place.

Ground truths

Facebook is a major online presence around the world. Take Africa, where it often ranks first or second in popularity among websites. Yet Facebook doesn't have data centers there, which means content generated by Facebook members in Kenya, for example, has to

traverse undersea fiber-optic cables to data centers on other continents. That costs local ISPs at least $100 per month for each megabit of traffic. This charge wouldn't apply if Facebook stored user content locally.

The ISPs pass those extra costs on to consumers—which surely can't help Internet expansion efforts on a continent where only 16 percent of people have Internet access, compared with 39 percent worldwide. "It's a bit disingenuous," says Phares Kariuki, who runs Angani, a cloud computing startup in Nairobi. "On the one hand, Facebook claims to want to give Africa access through Internet.org, but when it comes to the business decisions they are making, as far as Africans are concerned, I have not seen anything that reflects that value yet." (It is worth noting, however, that Akamai, the Web optimization service, is establishing infrastructure in more and more African locations. To the extent that Facebook uses Akamai's service, it reduces the extra costs that ISPs in those regions would incur.)

As part of Internet.org, Zuckerberg published a white paper titled "Is Connectivity a Human Right?" in which he wrote that the company has "invested more than $1 billion to connect people in the developing world over the past few years." But the details were absent: spent on what, to connect whom, and to what? Through a spokesman, Zuckerberg turned down an interview request. But on closer inspection, that statement apparently means "connect people to Facebook."

Facebook spokesman Derick Mains e-mailed a clarification: the company, he wrote, hasn't invested in any "physical buildout of infrastructure" to connect people. He declined to say where the $1 billion went, giving only one example: Facebook's $70 million purchase of Snaptu, whose technology makes it possible for apps like Facebook's to run on the basic phones that are common in developing countries.

Such acquisitions, of course, are meant to improve Facebook's own operations: the company, like others, is keenly interested in having its service accessible on as many phones as possible. Facebook is also doing important work to develop ways of delivering information more efficiently to smartphones that run the dominant Android operating system, says Jay Parikh, Facebook's vice president for infrastructure.

Casting Facebook's data efficiency plan as "the savior of the developing world" is "hard to swallow."

Facebook will surely come up with technologies that are useful on all kinds of mobile phones. But Ethan Zuckerman, who has helped lead several Web projects in poor countries, says that "to wrap that into a press release that turns Facebook into the savior of the developing world is hard to swallow."

Tapping the airwaves

Other Internet companies have gone much further, funding Internet infrastructure projects that also happen to advance their own interests in getting more people to use their services.

One is in the capital city of Kampala, Uganda, a metropolis where you can get relatively slow connectivity from any of about 10 mobile carriers or Internet service providers. In November, Google announced that it had installed 170 kilometers of fiber-optic lines in Kampala, a major step forward that could enable local carriers and ISPs to provide faster speeds at lower prices. (Fewer than 1 percent of sub-Saharan Africans have fixed broadband, defined by the U.N.'s International Telecommunication Union as a data rate of two megabits per second; 11 percent have mobile broadband, defined as 3G or similar service.)

A handful of other projects are meant to provide Internet access where none previously existed at all. One is unfolding in the region around Nanyuki, Kenya, a town at the foot of Mount Kenya. In poor and sparsely populated areas like this, extending fiber makes no sense economically—wireless carriers often fail to recoup their investments in even conventional cellular base stations powered by diesel generators. But in Nanyuki, an experimental low-cost wireless Internet system is radically altering the economics.

It works like this: first, a powerful microwave transmitter delivers a high-bandwidth connection from a fiber terminus to several fixed wireless base stations over tens of kilometers. These base stations retransmit data on unused television frequencies—called "white spaces"—to 40 solar-powered Wi-Fi routers and phone-recharging stations in schools, clinics, businesses, and community centers. The Nanyuki apparatus already serves 20,000 people, and this capacity is set to triple. Most important, it does so for less than $5 per user per month—5 percent of the region's average annual income of $1,200.

The company behind this effort is Microsoft, but Google has just completed a similar trial to provide bandwidth to schools in Cape Town, South Africa. Companies are testing many other white-space efforts around the world. The impact could be large: what many places need is simple access to the airwaves, which is frequently restricted by national governments. "If you look around the world—whether in the U.S. or the Philippines—the issues around digital inclusion and universal access are mainly policy challenges," says Paul Garnett, director of Microsoft's technology policy group.

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Reaching the remotest

But white spaces are only as good as the base stations and power supplies at the farthest endpoints. Vanu Bose, CEO of a company called Vanu that develops cheap cellular base stations, tells the story of an enterprising man in Zambia who collects cell phones every morning from his fellow villagers. He then drives three hours to a spot where he can get a signal from a cellular tower—and switches on all the phones so they can ingest all the text messages and voice mails that have accumulated since the previous day's excursion.

This workaround is a reminder that there are still more than 200 million people in Africa alone who don't even have the most basic cellular phone service. For Zambia, Bose has developed what he claims is the lowest-power base station on the market: a rugged unit that can connect to the Internet in a number of ways, including microwave links, satellite links, and white spaces, and serve up access to 1,000 villagers per node. All it needs is 50 watts of power from solar panels, with a few watts left over for a communal phone-charging dock. This provides very basic voice and data service and maybe one low-bandwidth Wi-Fi hot spot.

Broadband it ain't. But such service can be transformational—enabling families to stay in touch, emergency medical aid to be summoned, educational materials to be delivered. "Internet.org is all about higher-capacity networks and more bandwidth," Bose says. "But we shouldn't think about bandwidth first but connectivity of any kind first. They are very different things. One communications transaction per day is infinitely better than zero."

Beyond hyperefficient setups like Bose's, Google has prototyped a new concept: fleets of solar-powered balloons in the stratosphere, networking among one another and beaming Internet connectivity to far-flung rural areas at speeds comparable to 3G. It's been criticized as a marketing stunt, and it may not even work. But in contrast to Facebook's effort to increase data efficiency, "at least it's funky and new, at least it's interesting, at least it's ambitious," says Ethan Zuckerman, who today is director of the Center for Civic Media at MIT's Media Lab.

Facebook says its focus is in the right place, and that helping more people who already own phones to afford data plans is a crucial job. That's why the broad outlines of Internet.org involve figuring out how to deliver data more efficiently, in part through new business models. "A good way to look at it is that it's a first step, and a really hard problem to solve," says Aaron Bernstein, a former Qualcomm executive who is now a director of mobile partnerships at Facebook. And all the companies and organizations promoting and working toward Internet connectivity agree that there will be no silver bullet. "Only a lot of lead bullets," as Facebook's Parikh puts it.

If Facebook really wants to connect more people, it should support cutting-edge wireless networks.

But Facebook must shoot those bullets at the right targets. If the company really wants to make access more affordable, it can make sure its data is in the countries where people are using the service. If it really wants to connect more people, it can fund and support cutting-edge wireless networks. As John F. Kennedy said about the Peace Corps, 24 years before Zuckerberg was born: "Americans are willing to contribute. But the effort must be far greater than we have ever made in the past."

David Talbot is chief correspondent at MIT Technology Review.

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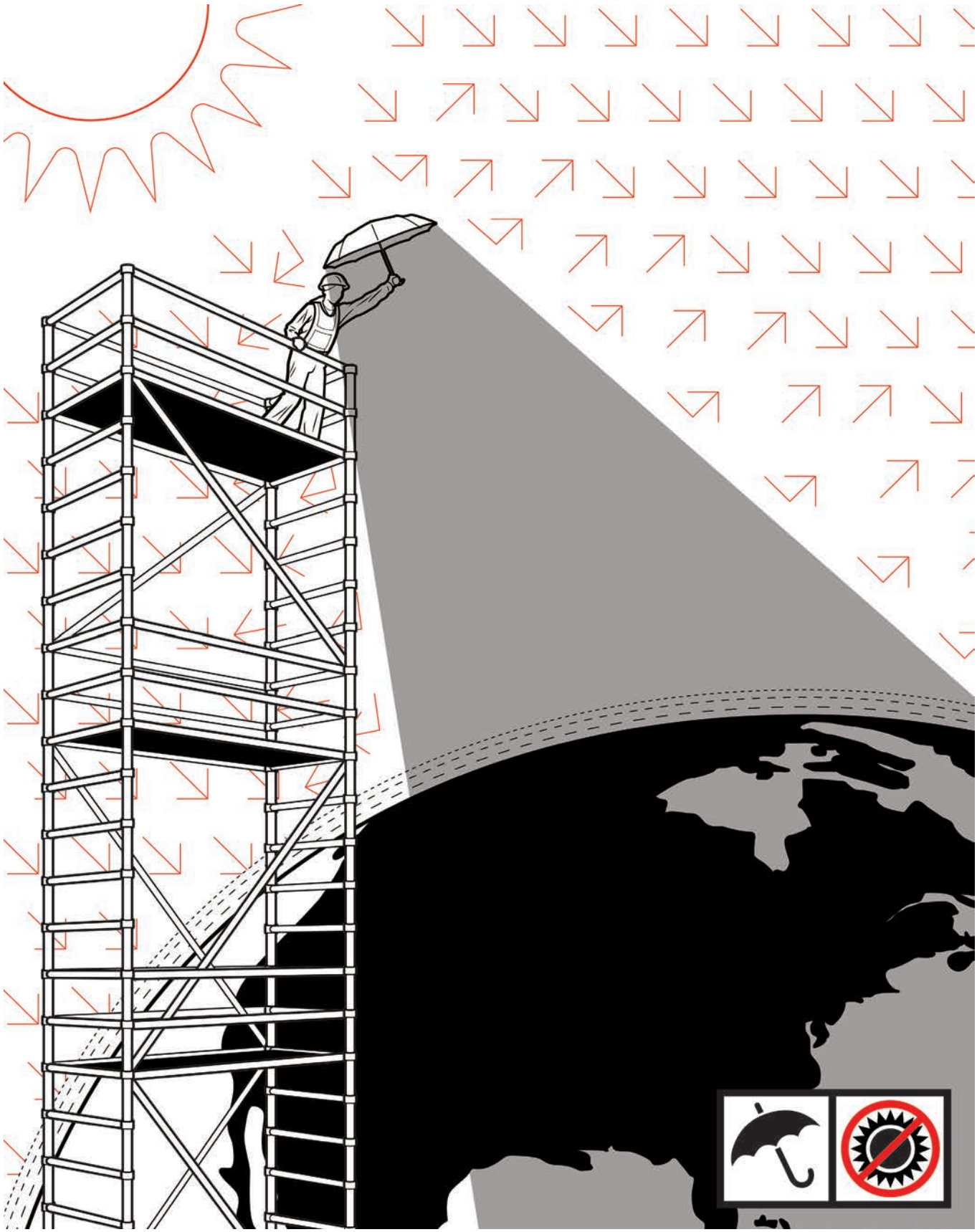

The Geopolitics of Geoengineering

Does humanity's tightening grip on the fate of nature portend new sources of global conflict?

By Eli Kintisch

More than a decade ago, Paul Crutzen, who won the 1995 Nobel Prize in chemistry for his research on the destruction of stratospheric ozone, popularized the term "Anthropocene" for Earth's current geologic state. One of the more radical extensions of his idea—that human activity now dominates the planet's forests, oceans, freshwater networks, and ecosystems—is the controversial concept of geoengineering, deliberately tinkering with the climate to counteract global warming. The logic is straightforward: if humans control the fate of natural systems, shouldn't we use our technology to help save them from the risks of climate change, given that there's little hope of cutting emissions enough to stop the warming trend?

In recent years a number of scientists—including Crutzen himself in 2006—have called for preliminary research into geoengineering techniques such as using sulfur particles to reflect some of the sun's light back into space. With the publication of *A Case for Climate Engineering*, David Keith, a Harvard physicist and energy policy expert, goes one step further. He lays out arguments—albeit hedged with caveats—for actually deploying geoengineering. He says that releasing sun-blocking aerosol particles in the stratosphere (see "A Cheap and Easy Plan to Stop Global Warming," March/April 2013) "is doable in the narrow technocratic sense."

Indeed, Keith is steadfastly confident about the technical details. He says a program to cool the planet with sulfate aerosols—solar geoengineering—could probably begin by 2020, using a small fleet of planes flying regular aerosol-spraying missions at high altitudes. Since sunlight drives precipitation, could reducing it lead to droughts? Not if geoengineering was used sparingly, he concludes.

Australian ethicist Clive Hamilton calls the book "chilling" in its technocratic confidence. But Keith and Hamilton do agree on one thing: solar geoengineering could be a major geopolitical issue in the 21st century, akin to nuclear weapons during the 20th—and the politics could, if anything, be even trickier and less predictable. The reason is that compared with acquiring nuclear weapons, the technology is relatively easy to deploy. "Almost any nation could afford to alter the Earth's climate," Keith writes. That fact, he says, "may accelerate the shifting balance of global power, raising security concerns that could, in the worst case, lead to war."

A Case for Climate Engineering
David Keith
MIT Press, 2013

The potential sources of conflict are myriad. Who will control Earth's thermostat? What if one country blames geoengineering for famine-inducing droughts or devastating hurricanes? No treaties ban climate engineering explicitly. And it's not clear how such a treaty would operate.

Keith professes ambivalence about whether humans are truly able to wield such powerful technology wisely. Yet he feels that the more information scientists uncover about the risks of geoengineering, the lower the chances the technology will be used recklessly. Though his book leaves unanswered many of the questions that arise over how to govern geoengineering, a policy paper that he published in *Science* last year goes further to address them: he and a coauthor proposed government authority over research and a moratorium on large-scale geoengineering but said there should be no treaties regulating small-scale experiments.

Hamilton says this approach would lead nations on a path toward the conflict that he thinks would inevitably surround geoengineering. Allowing lightly regulated small experiments, he suggests, could undermine the urgency of political efforts toward cutting emissions. This, in turn, increases the possibility that geoengineering will be used, since failing to restrain emissions will leave temperatures rising. Hamilton accuses Keith of seeking a "naïve ... cocoon of scientific neutrality" and says researchers cannot "absolve themselves of responsibility for how their schemes might be used or misused in the future."

That may be true, but Keith deserves credit for directing attention to ideas he knows are dangerous. Accepting the concept of the Anthropocene means accepting that humans have the responsibility to find technological fixes for disasters they have created. But little progress has been made toward a process for rationally supervising such activity on a global scale. We need a more open discussion about a seemingly outlandish but real geopolitical risk: war over climate engineering.

Eli Kintisch is author of Hack the Planet: Science's Best Hope—or Worst Nightmare—for Averting Climate Catastrophe *(2010).*

Illustration by MCKIBILLO

Demo

Printing Batteries

New inks and tools allow 3-D printing of lithium-ion technology.

By Mike Orcutt
Photographs by Ken Richardson

Jennifer Lewis

By making the basic building blocks of bat-teries out of ink, Harvard materials scientist Jennifer Lewis is laying the groundwork for lithium-ion batteries and other high-performing electronics that can be produced with 3-D printers.

Although the technology is still at an early stage, the ability to print batteries and other electronics could make it possible to manufacture new kinds of devices. Think of self-powered biomedical sensors, affixed to the skin, that would continuously transmit vital signs to a smartphone.

Or existing products could be made more simply and efficiently. For example, the plastic shell of a hearing aid is already

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02

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04

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01 To make inks used to print anodes for lithium-ion batteries, nanoparticles of lithium titanium oxide are added to a vial of deionized water and ethylene glycol.

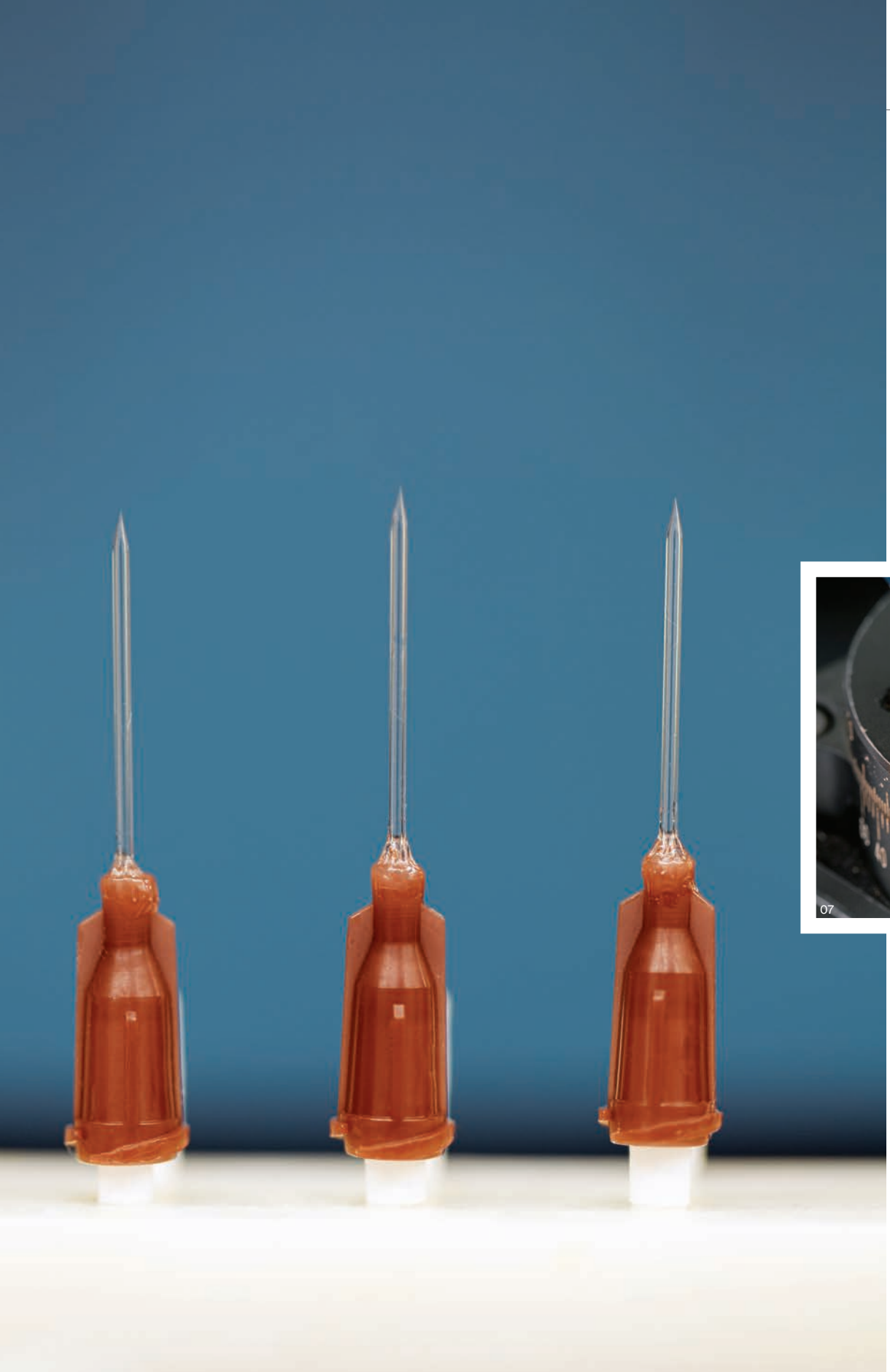
02 Ceramic balls are added to the mixture to act as grinders that will break apart the clumped particles.

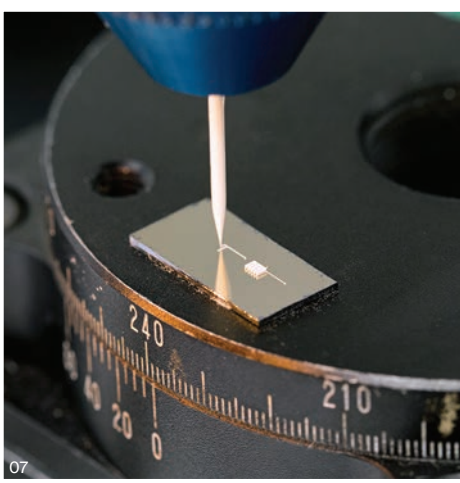
03 The mixture is spun for 24 hours, after which the balls and larger particles are removed using filters and a centrifuge.

04 The resulting ink, placed in a syringe, is now ready for use in a standard 3-D printer.

05 The syringe is inserted into a blue high-pressure dispenser added to a conventional 3-D printer. The ink is solid when unperturbed but flows under high pressure. It returns to a solid state once it leaves the syringe.

06





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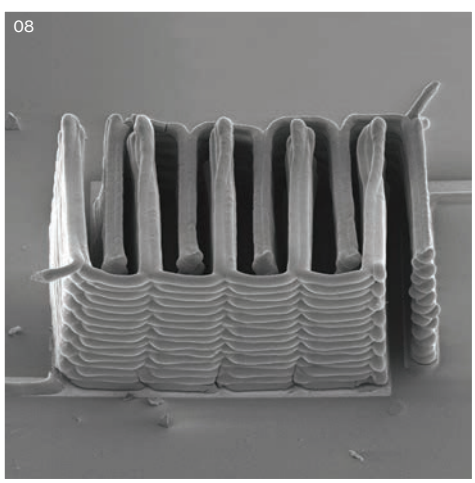
06 Custom-made syringe nozzle tips, as small as one micrometer wide at the opening, allow precise patterning.

07 White anode ink is extruded on a glass substrate. In practice, it would be printed atop a gold current collector patterned on the glass.

08 An array of anodes, each about one millimeter square, awaits a second step: printing the cathodes.

09 A micrograph shows a printed battery one millimeter square, with anodes and cathodes in a finger-like configuration.



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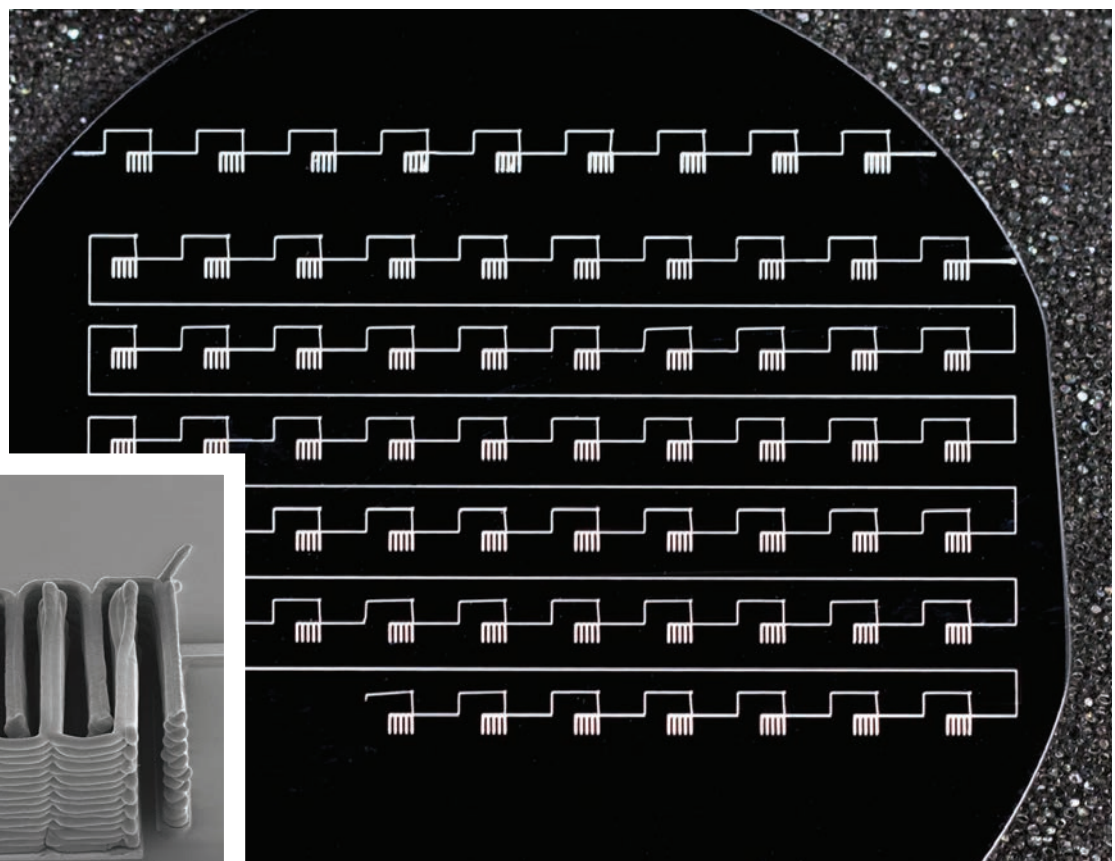


09

3-D printed for a custom fit inside a wearer's ear. But the electronics are manufactured separately, and the batteries are often the type that must be replaced frequently. If the electronics and a rechargeable battery were printed together, the final product could be made more rapidly and seamlessly.

Lewis has taken two important steps toward printing electronic devices. First, she has invented an arsenal of what she calls functional inks that can solidify into batteries and simple components, including electrodes, wires, and antennas. Second, she has developed nozzles and high-pressure extruders that squeeze out the batteries and other components from an industrial-grade 3-D printer.

The printing technology works at room temperature, not the high temperatures normally required to work with high-performing electronics. That makes it possible to print the materials on plastic without causing damage. The battery materials themselves aren't revolutionary, she says; "this is really more a revolution in the way things are manufactured."

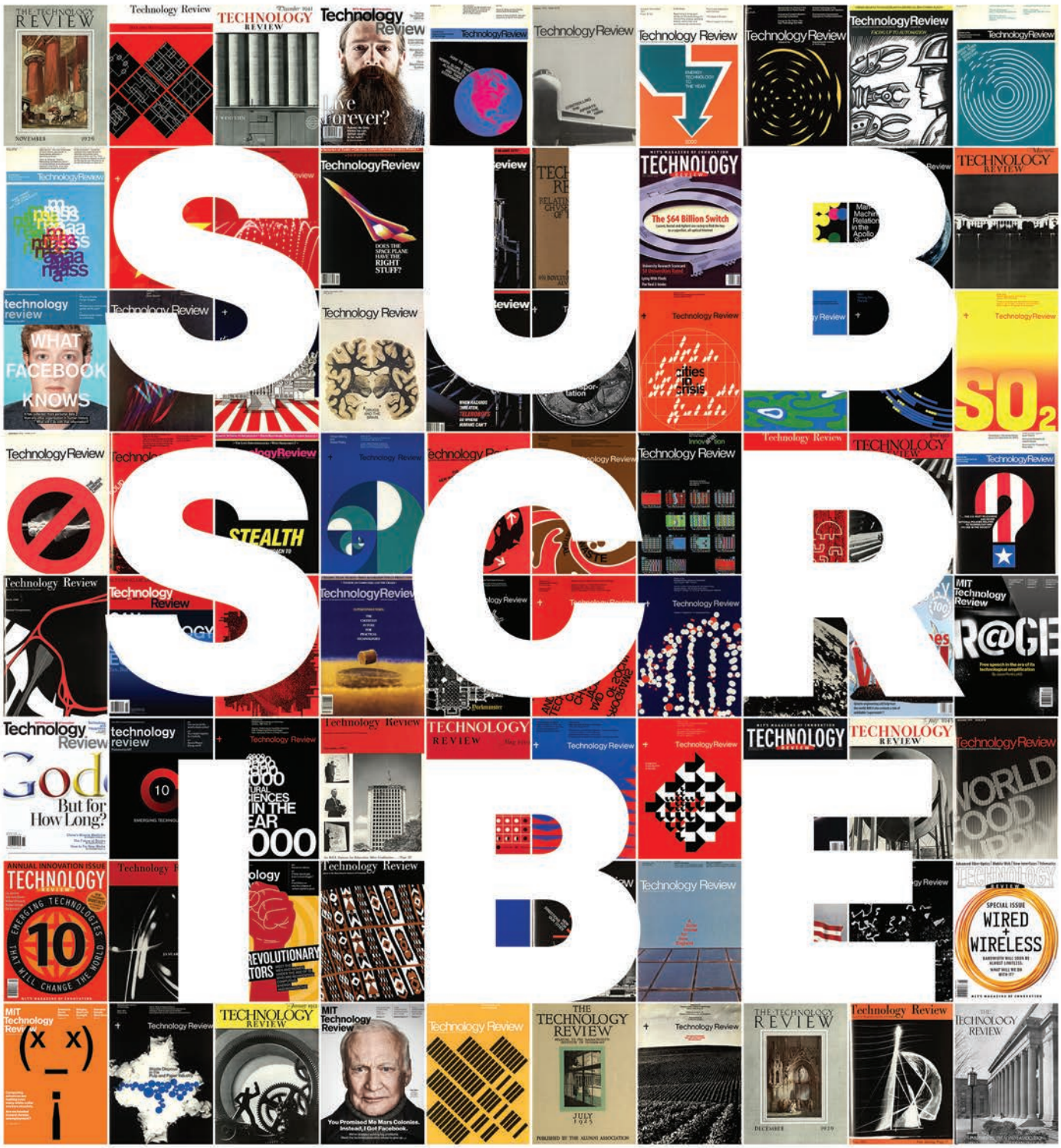
Lewis's inks use suspended nanoparticles of the desired materials, such as compounds of lithium for batteries and silver for wires. These materials are mixed into a variety of solutions, and the resulting inks are nearly solid when unperturbed but flow when a certain amount of pressure is applied. Once printed, the materials return to solid form.

Printing a battery from a single nozzle can take minutes, but Lewis's custom 3-D printing technology can deposit inks from hundreds of nozzles at the same time.

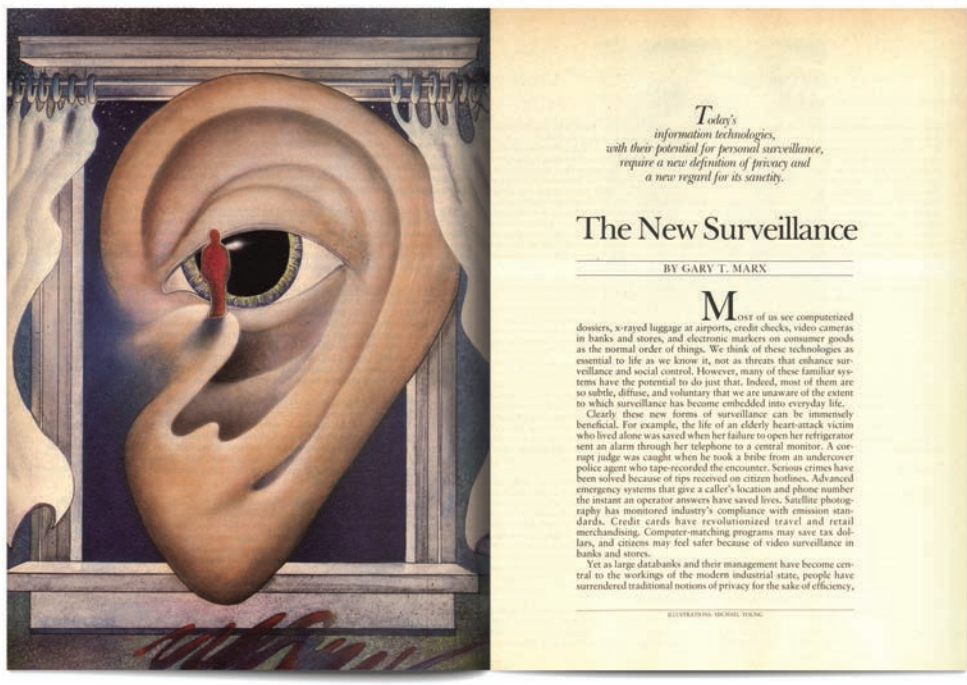
Her printed lithium-ion batteries are as tiny as one millimeter square but perform as well as commercial batteries, because Lewis can render microscale architectures, and position structures with 100-nanometer accuracy, to mirror the structures of much bigger batteries.

Lewis's group holds eight patents for its inks and is working on licensing and commercializing the technology in the next few years. Although she says the initial plan is to provide tools for manufacturers, she may eventually produce a low-end printer for hobbyists. T

PORTRAIT AND MICROGRAPH COURTESY OF JENNIFER LEWIS GROUP



29 Years Ago



Today's information technologies, with their potential for personal surveillance, require a new definition of privacy and a new regard for its sanctity.

The New Surveillance

BY GARY T. MARX

Most of us see computerized dossiers, x-rayed luggage at airports, credit checks, video cameras in banks and stores, and electronic markers on consumer goods as the normal order of things. We think of these technologies as essential to life as we know it, not as threats that enhance surveillance and social control. However, many of these familiar systems have the potential to do just that. Indeed, most of them are so subtle, diffuse, and voluntary that we are unaware of the extent to which surveillance has become embedded into everyday life.

Clearly these new forms of surveillance can be immensely beneficial. For example, the life of an elderly heart-attack victim who lived alone was saved when her failure to open her refrigerator sent an alarm through her telephone to a central monitor. A corrupt judge was caught when he took a bribe from an undercover police agent who tape-recorded the encounter. Serious crimes have been solved because of tips received on citizen hotlines. Advanced emergency systems that give a caller's location and phone number the instant an operator answers have saved lives. Satellite photography has monitored industry's compliance with emission standards. Credit cards have revolutionized travel and retail merchandising. Computer-matching programs may save tax dollars, and citizens may feel safer because of video surveillance in banks and stores.

Yet as large databanks and their management have become central to the workings of the modern industrial state, people have surrendered traditional notions of privacy for the sake of efficiency,

ILLUSTRATIONS: MICHAEL YOUNG

Selling Privacy Short

Technologies that make life easier also make it simpler to track your every move, warned *Technology Review* in 1985.

Modern surveillance technologies now allow organizations to monitor people's movements to a degree previously imagined only in fiction. Aircraft that can spot a car or person 30,000 feet below have been used to monitor drug traffickers. Satellites may soon be used for this purpose as well. The CIA has apparently used satellite photographs to monitor antiwar demonstrations and civil disorders. Computer enhanced satellite photography can identify vehicles moving in the dark. One-way video and film surveillance has expanded rapidly, as anyone who ventures into a shopping mall or uses an electronic bank teller should realize.

Other devices now in use include sensitive miniature but powerful radio transmitters; tape recorders the size of a match box; video cameras the size of a deck of cards; instruments for detecting motion, air currents, vibrations, odor, and pressure changes; and voice-stress analyzers.

The National Security Agency can simultaneously monitor 54,000 telephone transmissions to and from the United States. The agency operates beyond the usual judicial and legislative controls, and can apparently disseminate its information to other government agencies at will.

Citizens' ability to evade all this surveillance is diminishing. To venture into a shopping mall, bank, or subway, sometimes even into a bathroom, is to perform before an unknown audience.

To avoid such intrusions, people may decline needed services such as mental-health care, and avoid controversial actions such as filing grievances against governments. We may shun risks and experiments as the new technology exerts subtle pressure for conformity at the expense of diversity, innovation, and vitality.

In a society where everyone feels as if he or she is a target for investigation, trust—the most sacred element of the social bond—is damaged. Indeed, today's surveillance technologies may be creating a climate of suspicion from which there is no escape."

Excerpted from "The New Surveillance," by Gary T. Marx, originally published in the May/June 1985 issue of Technology Review.

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